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FIRE DEPARTMENT PERSPECTIVE: CROWD DYNAMICS AND SAFETY AT OUTSIDE EVENTS

by

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13. ABSTRACT (maximum 200 words)

Fire departments often respond to incidents at crowded events with no prior planning or coordination with other agencies. The result can be decreased safety for patrons at the events. The purpose of this thesis is to understand causes of injuries at crowded, outside venues and what could make these events safer. This thesis asks how fire department personnel can plan for the safety and care of large crowds at outside venues. The research design includes a review of literature on crowd dynamics and example incidents. Using root cause analysis, this thesis analyzes four case studies: 1989 Hillsborough soccer match, 2011 Reno Air Race, the 2013 Boston Marathon bombing, and 2014 Travis Air Force Base Air Show. The success of the Reno Air Race and Boston Marathon rescue personnel in taking care of injured victims can be attributed to careful planning by stakeholders before the events took place. This thesis recommends that before large, crowded events, stakeholders establish relationships and that all stakeholders participate in careful planning and realistic training. This planning and training should include interoperability of communications, roles for volunteer staff, and ways to prevent and decrease overcrowding. Finally, this thesis recommends strategies to educate event patrons on safety.

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FIRE DEPARTMENT PERSPECTIVE: CROWD DYNAMICS AND SAFETY AT OUTSIDE EVENTS

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ABSTRACT

Fire departments often respond to incidents at crowded events with no prior planning or coordination with other agencies. The result can be decreased safety for patrons at the events. The purpose of this thesis is to understand causes of injuries at crowded, outside venues and what could make these events safer. This thesis asks how fire department personnel can plan for the safety and care of large crowds at outside venues. The research design includes a review of literature on crowd dynamics and example incidents. Using root cause analysis, this thesis analyzes four case studies: 1989 Hillsborough soccer match, 2011 Reno Air Race, the 2013 Boston Marathon bombing, and 2014 Travis Air Force Base Air Show. The success of the Reno Air Race and Boston Marathon rescue personnel in taking care of injured victims can be attributed to careful planning by stakeholders before the events took place. This thesis recommends that before large, crowded events, stakeholders establish relationships and that all stakeholders participate in careful planning and realistic training. This planning and training should include interoperability of communications, roles for volunteer staff, and ways to prevent and decrease overcrowding. Finally, this thesis recommends strategies to educate event patrons on safety.

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LIST OF ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AHJ	authority having jurisdiction
ARFF	aircraft rescue and firefighting
CERT	Citizens Emergency Response Team
DOE	Department of Energy
EMS	emergency medical service
FAA	Federal Aviation Administration
IAP	incident action plan
ICS	Incident Command System
ISO	Insurance Services Office
NFPA	National Fire Protection Association
NTSB	National Transportation Safety Board
P-51D	Pursuit-51 (D) model
RARA	Reno Air Race Association
SYFC	South Yorkshire Fire Commission
UASI	Urban Area Security Initiative
UC	unified command

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EXECUTIVE SUMMARY

This thesis seeks to determine how fire departments can plan for the safety and care of people in large crowds at outside venues. It is important for fire departments to understand crowd dynamics and behavior as they attempt to oversee safety for the large, dense crowds. The thesis analyzes crowd behavior by examining incidents that happened at large crowded events. These events provide insight about crowd reaction to unexpected incidents at large outdoor events and resulting safety concerns. However, there is not comprehensive data available on these events through impartial government sources. Therefore, the thesis also analyzes four case studies: the 1989 Hillsborough soccer match, the 2011 Reno Air Race, the 2013 Boston Marathon, and 2014 Travis Air Force Base Air Show, all of which include tragic events and have government, open-source material available for analysis. The resulting data supports recommendations for fire departments on improved safety at future crowded venues.

Crowds move in both predictable and unpredictable patterns.[1] Large outdoor events can draw crowds ranging from 1,000 people, up to or easily exceeding 100,000 people, all moving around in the crowd independently or as one group, mimicking fluid movement.[2] Routinely, events such as inaugurations, golf tournaments, bicycle races, marathons, sporting events, and air shows generate huge groups.

This thesis uses a systematic approach to conduct research. The first step of the research is to understand how crowds move and what determines their movement. This thesis also examines strategies for crowd management to prevent injuries and to deliver care when there are injuries. The information comes from open sources, including sources such as after-action reports, journals, newspaper articles, and reports of boards of inquiry; however, sources are limited to historical public events, since practical experimentation of actual crowd conditions may not be safely replicated in a research scenario. The next step

[1] G. Keith Still, *Introduction to Crowd Science* (Boca Raton: CRC Press, 2013).

[2] Dirk Helbing, Anders Johansson, and Habib Zein Al-Abideen, "The Dynamics of Crowd Disasters: An Empirical Study," *Physical Review E* 75, no. 4 (2007): https://doi.org/10.1103/PhysRevE.75.046109.

is identification and analysis of common problems that responders encounter in trying to deliver aid and care at large events. For the third step, this researcher conducted case study analysis to examine crowd behavior and response issues together.

This research uses root cause analysis in the four case studies to identify causal factors leading to deaths and injuries.[3] Using Department of Energy guidance on the procedure for root cause determination, the first phase in determining root cause is to identify the specific problem rather than the unintended occurrence that resulted. The second phase is to determine the importance of the incident with regard to injuries that happen at the events and what may have caused them. The third phase is to identify the cause of the incident by examining the pre-event risk assessment. The last phase is to find the cause by starting at the end of the incident and working backward toward the beginning of the incident to determine what factors may have caused the incident.[4]

The data gleaned from examining the literature and the root cause analysis of the case studies reveals some common problems caused by human behavior and interaction during emergencies at crowded events. Some of the problems noted are overcrowding, incidents caused by human error, and issues with communications. The results of that behavior can cause injuries or deaths almost instantaneously, as it did at the Hillsborough soccer match on April 15, 1989, when 96 people died and hundreds were injured. The cause of the deaths was compressive asphyxia, a condition resulting in the inability to breathe.[5] However, the reason people died and were injured was due to improper actions taken by the police on scene, who mistakenly opened a gate and allowed thousands of soccer fans to rush into confined areas that were not meant to hold the number of people who surged in.[6]

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[3] U.S. Department of Energy, *Root Cause Analysis Guidance Document* (DOE-NE-STD-1004-92) (Washington, DC: U.S. Department of Energy, 1992), https://www.standards.doe.gov/standards-documents/1000/1104-std-1992/@@images/file.

[4] Ibid., 1.

[5] Helbing, Johansson, and Zein Al-Abideen, "The Dynamics of Crowd Disasters," 5.

[6] Patrick Sawer, "What Happened at Hillsborough in 1989?," *The Telegraph*, April 15, 1989, http://www.telegraph.co.uk/news/0/happened-hillsborough-1989/.

As previously stated, the reactions by the crowd and the police were the result of human behavior. Additional findings of this research reveal that people walk at different speeds (some slower, some faster), and people moving at different speeds in a dense crowd can affect the ability of others to move effectively. Venues that are densely crowded also inhibit the ability of people to move freely, which may cause some to fall or trip. The most densely populated crowds are unable to stop moving to allow a fallen person to get up or be assisted, and this can result in injury or death. People who have fallen in a dense crowd become trip hazards for the moving crowd, which then has to change direction to avoid the person; however, given crowd size and momentum, it may not always be possible for the crowd to avoid a fallen person. Additionally, barriers, like turnstiles or fencing, that are improperly placed at venues to direct crowd movement can slow the movement of people, causing bottlenecks and potential injury.

Preventing injury is paramount at crowded events, and this responsibility falls to fire departments and other emergency responders. This research found that staging emergency personnel and their equipment at strategic locations during events can decrease the response time for responders to reach patients and begin giving care. In turn, this increases the viability of severely injured patients, as demonstrated in the Boston Marathon and Reno Air Race case studies.

This research also found that communications is one of the most important factors in these events. Furthermore, communications were specifically a problem at Hillsborough soccer match, but a tremendous help at both Boston Marathon and Travis Air Show, where responders had interoperable radios and a public address system, respectively. The positive responses received from after-action reports indicate that planning and training prior to an event produces a cohesive group of emergency responders who work well together.

Recommendations for future outside venues include the development of a standard planning program involving all fire department and emergency services, including all related public service agencies that will be associated with an event, and the planning should be specifically tailored proposed location of the event. The program should not only provide a plan for emergency response, but it should also include tabletop exercises and live drills, such as used in the Reno Air Race and Boston Marathon before the events, to develop and deliver the skills of stakeholders and staff that are needed to achieve public safety and care.

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I. THE FIRE DEPARTMENT PERSPECTIVE: PROVIDING CROWD SAFETY DURING DYNAMIC EVENTS

Crowds move in both predictable and unpredictable patterns.[1] Large outdoor events can draw crowds ranging from a 1,000 people up to or easily exceeding 100,000 people, all moving around in the crowd independently or as one group, mimicking fluid movement.[2] Routinely, events such as inaugurations, golf tournaments, bicycle races, marathons, sporting events, and air shows generate huge groups. Researchers like Still, Helbing, Fahy, Proulx, and Aiman have studied similar venues analyzing data to form a possible solution for preventing injury from sudden movement of people in densely populated events.

A. PROBLEM SPACE

The movement, size, density, and complexity of crowds at large, outdoor events may make it difficult to plan for the safety of patrons, including their ability to safely egress.[3] People's dynamic movement may be triggered by looking for food, attractions, or bathrooms.[4] People who formed groups within crowds and are moving in a particular direction may encounter other groups that have formed in the crowd and are moving in a different direction. When this happens, each group will try to take a path of least resistance.[5] This can cause the other groups in the crowd to change their direction of travel as well. The effect is rather like swirling eddies in turbulent water. When crowd size and density increase, it can compound these turbulent effects because the larger and denser a crowd is, the more difficult it is for individuals to move independently within the crowd.[6] Obstacles that prohibit smooth travel of crowds add complications to the movement and

[1] G. Keith Still, *Introduction to Crowd Science* (Boca Raton: CRC Press, 2013).

[2] Dirk Helbing, Anders Johansson, and Habib Zein Al-Abideen, "The Dynamics of Crowd Disasters: An Empirical Study," *Physical Review E* 75, no. 4 (2007), https://doi.org/10.1103/PhysRevE.75.046109.

[3] G. Keith Still, *Introduction to Crowd Science* (Boca Raton: CRC Press, 2013).

[4] Ibid., 38.

[5] Ibid.

[6] Ibid.

direction of individuals or groups in those crowds. These obstacles can include strollers, wheelchairs, and people who travel at different speeds.[7] An emergency affecting the crowd can result in injuries, resulting in ineffective movement to exits and safety. Fire departments are tasked with assisting the injured and attempt to provide crowds with safe passage to exits.

Emergencies at outdoor venues arise from unexpected events affecting crowd's safe movement and departure. The incidents can result in injury anywhere from a few people to several hundred people or more. When members of a crowd are injured, it can cause others in the crowds to move quickly to try and get to safety; this more difficult in denser, larger crowds. An example of a high-risk, low-frequency event may be one due to weather, an earthquake, terrorist activity, or another emergency. An emergency situation with a crowd can inhibit people's safe passage to an exit, causing the group to move in unpredictable patterns and keeping the fire department from efficiently assisting. The result may be an increase in injuries, which overwhelms available resources. The inevitability of incidents involving injuries is an obvious concern at crowded events.[8]

A better understanding of what causes crowd movement may help firefighters assigned with public safety at events to prevent injury. It is essential to understand what causes crowd movement to avert injury entirely. Designing safety features and implementing them prior to an event is vitally important for prevention of injury as well.[9] G. Keith Still has been studying crowd dynamics for more than 25 years to make people safe at large venues and attributes prevention and preparedness to provide the answer.[10] One method for understanding crowd movement and planning for safe exiting is through the use of computer modeling software to determine crowd movement and size, as well as the direction of its flow in an emergency. Ed Galea, Director of Fire Safety Engineering

[7] Ibid., 121.

[8] G. Keith Still, "Crowd Dynamics: Thesis" (PhD. Diss., University of Warwick, 2000), http://www.gkstill.com/Support/Links/Documents/2000_still.pdf, 26.

[9] Still, *Introduction to Crowd Science*.

[10] Still, "Crowd Disasters; Thesis," 39.

Group at the University of Greenwich developed Exodus software.[11] The software can produce effective results to allowing a smoother transition of people through an exit through large events, thereby decreasing injury and death in an emergency.[12] It is designed to work with existing structures and to help develop new buildings, aircraft, and venue safety. The Exodus computer modeling program can simulate buildings, outdoor venues, aircraft and is scalable to match any number of prospective patrons. It can mimic decisions by individuals and simulate the responses and results during an emergency.[13] Different exits and conditions may also be added to the program to anticipate the paths that people will follow to leave an area safely.[14]

Prevention is critical to sustaining the safety of individuals.[15] It is therefore much easier to teach the public how to prevent injury with education about safety and exiting at large venues than how to recover from an injury sustained. It is also essential to determine effective procedures and training for operations during an emergency. When firefighters operate professionally and competently during an emergency incident, it decreases the probability of additional injuries to people and increases the possibility of survival for the injured.[16] This thesis explores elements of crowd movement and crowd dynamics during emergencies. The information obtained in this research will help determine how fire departments can better understand and implement efforts to prevent injury, provide care, and facilitate egress in emergencies. The complexity of large events, including the

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[11] Ed Galea, "Scientists Launch World's Most Advanced Crowd Simulation and Evacuation Software," Hemming Fire, January 10, 2012, http://hemmingfire.com/news/fullstory.php/aid/1416/Scientists_launch_world_92s_most_advanced_crowd_simulation_and_evacuation_software_.html.

[12] Andrew Lynch, "World's Most Advanced Crowd Simulation and Evacuation Software," *Fire Magazine*, January 10, 2012, https://www.fire-magazine.com/worlds_most_advanced_crowd_simulation_and_evacuation_software_12799.aspx.

[13] Ibid.

[14] Ibid.

[15] Joseph Manuse, "Gates Fire District," *Firehouse Magazine*, April 1, 2016, http://www.firehouse.com/article/12188146/fire-prevention-take-life-safety-messages; National Fire Protection Association, "NFPA 101," accessed February 26, 2017, http://www.nfpa.org/Assets/files/AboutTheCodes/101/BLDSAF-HEA_FDSupItemAgenda_08-12.pdf.

[16] Mark Wallace, "Strategic Planning for Training and Professional Development," *Fire Engineering* 162, no. 8 (2009), http://www.fireengineering.com/articles/print/volume-162/issue-8/features/strategic-planning-for-training-and-professional-development.html.

complexity of crowd dynamics and behavior, have hampered the ability of fire departments to formulate specific policies for their involvement in these types of events. The findings of this thesis will help to guide fire departments in the development of generalized policies and procedures for large events.

B. RESEARCH QUESTION

This thesis seeks to determine how fire departments can plan for the safety and care of people in large crowds at outside venues.

C. LITERATURE REVIEW

Large outdoor venues create fast, unpredictable movements of people that result in dynamic crowd responses. A crowd's density determines the ability for individuals in the crowd to move quickly (or not) in the direction they want to go. An emergency can amplify crowd response and increase the number of individuals injured, resulting in an increased response time for first responders to administer care. Research thus has provided limited information on the subject of crowd dynamics and safety from a fire department's perspective is limited. Therefore, sources from law enforcement research and studies of indoor venues related to exits in buildings and stadiums have been included.

1. Crowd Behavior

The field of crowd dynamics is not new and has been an area of concentrated study since 1995.[17] For example, G. Keith Still has worked for many years researching crowd movement and is considered a subject matter expert in the United Kingdom.[18] His research is related to all types of indoor and outdoor events and focuses on preventing injury. Still's research indicates that problems associated with crowds and their safety are a matter of misuse of space due to "design and management."[19] Additionally, his research also

[17] Dirk Helbing, Anders Johansson, and Habib Zein Al-Abideen, "The Dynamics of Crowd Disasters: An Empirical Study," *Physical Review E* 75, no. 4 (2007): https://doi.org/10.1103/PhysRevE.75.046109.

[18] Keith Still, "Prof. Still—Biography," last updated October 4, 2007, http://www.gkstill.com/CV/index.html.

[19] Still, "Crowd Disasters."

examines historical events resulting in injury and crowd management. This real-world information is of vital importance since it is not based on laboratory research alone. Still found that the key to developing a safe environment for people is through continued analysis of events and use of software programs as methods to prevent to crowd injuries.[20] Still also incorporates the use of mathematics and crowd density calculations to determine the maximum number of people who can safely attend an event.[21] He states that crowds having five people or fewer per square meter is safer and allows free movement of people, whereas crowds of six or more people per square meter present a potential disaster through "shockwaves."[22] Shockwaves, or crowd rush, which can cause injury or death, are created when people suddenly move unpredictably in a dense crowd.

In contrast to Still's approach to analyzing crowd dynamics, some scholars primarily use risk analysis to develop techniques for safety. One such expert is David Vose, who advocates eliminating the probability of an incident to decrease the occurrence of injury at events.[23] Vose has worked as a risk analysis consultant since 1988 and has written several books on the subject of risk. He differs from others in his process of analysis as he allows the problem to orchestrate the analysis, rather than developing a theory and then trying to prove it.[24] To determine risk for an outside venue with a large crowd, Vose looks at what he calls the "value of information" and uses the results to drive the possibility of risk by determining a cost.[25] Vose looks at the amount of money received at a venue, which produces a gross income and net profit. The income would be compared to the value or cost of an incident, thereby decreasing the net profit.[26] Although Vose's research is not specifically directed at large outside events, which is the focus of this thesis, he does

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[20] Still, "Crowd Dynamics: Thesis."

[21] Ibid., iii.

[22] G. Keith Still, "Introduction to Crowd Science," GKStill, last modified August 20, 2016, http://www.gkstill.com/Support/index.html.

[23] David Vose, *Risk Analysis: A Quantitative Guide* (Hoboken, NJ: John Wiley & Sons, 2008), 85.

[24] Vose recognized the works of Morgan and Henrion's research and related to his own. Vose, *Risk Analysis*.

[25] Vose, *Risk Analysis*.

[26] Ibid., 473.

provide information to educate individuals who assess risks of any type. For example, Vose tries to teach managers that proper risk management decreases the probability of an incident, thereby decreasing the number of people and equipment needed to achieve a goal safely and efficiently.[27] His strategy can be applied as easily to safe crowd management as to safety for cruise ships.

Karamouzas et al. use quantitative analysis and newly developed "physics-based animation software" to provide dependable and reliable simulations of crowd behavior while leaving a venue.[28] They note the different patterns of movement that crowds take while exiting through hallways, making lanes of traffic or a "zipper pattern," when converging from different directions.[29] Their findings, when applied to an emergency evacuation, are vitally important to fire, law, and emergency medical services (EMS) since crowds exhibit a different type of behavior during egress. Karamouzas et al. indicate the problems associated with a crowd exiting a venue during an emergency create stalls in the crowd, which develop congestion, and this in turn slows the progress of evacuation while increasing the likelihood of injury.[30]

Daichi Yanagisawa et al., graduate students at the University of Tokyo, have advocated for placing obstacles in predetermined locations near exits. Their ideas directly oppose conventional theory from other researchers like Karamouzas and his colleagues, who believe that obstacles slow exiting and create congestion.[31] No one had attempted this kind of approach previously. Ironically, the study by Yanagisawa et al. was inspired by empirical observations of obstacles slowing traffic.[32] They determined that putting barriers directly in front of exits attained few advantages; however, moving barriers slightly off

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[27] Ibid., 17.

[28] Ioannis Karamouzas et al., "Implicit Crowds: Optimization Integrator for Robust Crowd Simulation," *ACM Transactions on Graphics* 36, no. 4 (2017): Article 136, https://people.cs.clemson.edu/~ioannis/implicit-crowds/files/implicit_crowds.pdf.

[29] Ibid., 7.1.

[30] Ibid.

[31] Ibid.

[32] Daichi Yanagisawa et al., "Introduction of Frictional and Turning Function for Pedestrian Outflow with an Obstacle," *Physical Review E* 80, no. 3 (2009), https://arxiv.org/pdf/0906.0224.pdf.

center of the exit and at a prescribed distance gained a distinct advantage to speed exiting.[33] Yanagisawa et al. claimed the obstacles cause individuals to slow down and decide their path for exiting, thereby slowing their pace and preventing the possibility of knocking people down or injuring them as the crowd moves toward an exit in an emergency.[34] An important part of this study is the recognition that people *decide* the direction in which they move and that people take the time to consider options. Therefore, Yanagisawa et al. claim that people move more slowly while exiting when they encounter a barrier, giving them time to think about the direction to exit, resulting in faster exit times.[35]

Andreas Schadschneider, a professor at the University of Cologne's theoretical physics department, and his colleagues, Debashish Chowdhury and Katsuhiro Nishinari, oppose the approach of Yanagisawa et al.[36] In an interview by John Matson, a journalist for *Scientific American Magazine*, Schadschneider asserted that an obstacle-type egress would induce people to seek other exits and possibly create more problems and injuries.[37] He cited an example of an evacuation experiment of an A-380 Airbus aircraft in 2006 in which people sustained multiple injuries and one person had broken bones.[38] Schadschneider, Chowdhury, and Nishinari believe that an experiment cannot predict individual human behavior during an emergency, claiming an individual's ability to make decisions decreases during an emergency.[39] Their research supports the idea that people follow each other just as they do on a trail, one behind the other. Moreover, the time to exit safely decreases with each person following an unknown leader on the vague path.[40]

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[33] Ibid., 1.

[34] Ibid.

[35] Ibid., iv.

[36] Andreas Schadschneider, Debashish Chowdhury, and Katsuhiro Nishinari, *Stochastic Transport in Complex Systems: From Molecules to Vehicles* (Amsterdam: Elsevier, 2010).

[37] John Matson, "Strategically Placed Obstacle Near an Exit Can Speed Evacuations," *Scientific American*, August 28, 2009, https://www.scientificamerican.com/article/obstacle-exit-pedestrian/.

[38] Associated Press, "33 Injured in Safety Test for Airbus Super-Jumbo," *The Guardian*, March 27, 2006, http://www.theguardian.com/business/2006/mar/28/theairlineindustry.internationalnews.

[39] Schadschneider, Chowdhury, and Nishinari, *Stochastic Transport*.

[40] Ibid.

Schadschneider and his colleagues are not without opposition. For example, a report by Rita F. Fahy, Guylene Proulx, and Lata Aiman provide an alternative theory for people's behavior in emergencies.[41] Their work claims that the human response is not necessarily characterized as panic in an emergency but as that of calculated decision making.[42] Unfortunately, the human response is most often to exit in masse from the point of entry, as shown during the Stardust Nightclub fire in 1981.[43] Rather than recognizing there were other available exits, during the fire club patrons chose to go to the front doors through which they had initially entered the building. Some fell in a crowd crush and piled up, preventing others from escape. The results were similarly devastating during the Station Night Club fire in 2003, which killed 100 people and injured more than 200.[44] As with the Stardust incident, although many other exits went unused, people tried to exit through the same doors they entered, creating a human blockade as they fell.[45] Considering Schadschneider, Debashish, and Nishinari's theory, choosing to follow a line of people out of a building may not be the wisest decision.[46]

The research of Helbing and Johannsson aligns with that of Still in that they consider many possibilities for crowd behavior rather than standing on a single method like physics or animation.[47] Helbing and Johannsson have taken the time to analyze how and why people react the way they do to given situations. He then analyzes human behavior, such as attempting to pass known obstacles at a venue or in buildings, with different

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[41] Rita Fahy, Guylene Proulx, and Lata Aiman, "'Panic' and Human Behaviour in Fire," in *Proceedings of the 4th International Symposium on Human Behaviour in Fire* (Cambridge, UK: Robinson College, 2009), http://tkolb.net/FireReports/PanicInFire09.pdf, 387–398.

[42] Ibid.

[43] Ibid.

[44] "The Station Nightclub Fire," National Fire Protection Association, accessed February 25, 2017, http://www.nfpa.org/public-education/by-topic/property-type-and-vehicles/nightclubs-assembly-occupancies/the-station-nightclub-fire.

[45] Ibid.

[46] Schadschneider, Chowdhury, and Nishinari, *Stochastic Transport*.

[47] Dirk Helbing and Anders Johansson, *Pedestrian Crowd and Evacuation Dynamics* (Ithaca, NY: Cornell University, 2013), http://www.ethlife.ethz.ch/archive_articles/100727_Massenpanik_Helbing_sch/Pedestrian_Crowd_and_Evacuation_Dynamics_Helbing.pdf.

configurations to determine outcomes.[48] This information can be applied to outdoor events where buildings, cars, or other barriers may be a factor in crowd movement. Helbing and Johansson consider human reasoning in developing his theories just as Schadschneider, Chowdhury, and Nishinari believe that individual decisions play a major role in the human response and can lead to injury at crowded event.[49] Helbing and Johannsson also explain that people have different gaits, which affect their ability to exit a venue. One must also consider age, disability, and the use of prostheses in determining a person's mobility and self-transport. When personal mobility becomes disrupted, a person's direction of choice can no longer be predetermined, which can create chaos and change the outcome of one's intended path of travel.[50] Exiting problems were put to the test in a 1990 scenario to help make egress from an aircraft safer after an aircraft incident a few years prior.[51]

Britain's Civil Aviation Authority asked Helen Muir, psychologist and researcher, and her colleague, Clair Marrison, to develop safe aircraft-exiting procedures after the Boeing Flight 28 disaster in Manchester, England in the 1980s.[52] The pilots believed their aircraft had punctured a tire during take-off. In reality, an engine failure had occurred and started a fire in the aft portion of the plane's cabin.[53] The pilots stopped the aircraft before taking off as the fire spread in the cabin, killing 55 people, mostly by smoke inhalation.[54] Passengers were unable to find exits in the smoke-filled cabin, and some exit doors were jammed, preventing passengers opening them.[55] Muir and Marrison determined that it was both features of the plane and airline procedures that killed the passengers.[56] Their work is

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48 Helbing and Johansson, *Pedestrian Crowd*.

49 Matson, "Strategically Placed Obstacle."

50 Helbing and Johansson, *Pedestrian Crowd*.

51 Helen Muir and Claire Marrison, "Human Factors in Cabin Safety," *Cabin Crew Safety* 25, no. 2 (1990): 1–6, https://flightsafety.org/ccs/ccs_mar-apr90.pdf.

52 Ibid.

53 Tom Mullen, "A Defining Disaster for Air Travel," *BBC News*, August 17, 2015, http://www.bbc.com/news/uk-england-manchester-33304675.

54 Ibid.

55 Ibid.

56 Muir and Marrison, "Human Factors."

particularly relevant to the focus of this thesis, which is how to move a group of individuals, without harm, in an emergency through a safe exit at a large event.

Researchers have used models and participants to develop a conclusive answer to problems associated with trying to move many people during an emergency. However, the admittedly tricky aspect of such studies, as pinpointed by Schadschneider, Chowdhury, and Nishinari, have been replicating actual emergency conditions in an experimental environment.[57] To address this problem, Muir and Marrison introduced a simple concept: they paid individuals to exit the plane as quickly as possible and rewarded those who exited first.[58] Interior footage of the experiment in the aircraft revealed the chaotic and aggressive movements of participants, the same behavior as passengers on Flight 28. Muir and Marrison realized several things that could be changed to help facilitate the safe exit of passengers in emergencies. First, it was necessary to have illuminated pathways to see a trail to exit locations in smoke-filled cabins. Next, the width of bulkhead openings—the passageway itself—could be increased to provide swifter exiting. More importantly for Muir and Marrison was the need to take decision making away from people by training flight crews to aggressively assist passengers while exiting a plane during an emergency.[59] Essentially, Muir and Marrison recommended that crew members be strategically placed in the cabin and physically help passengers to exit.[60] Their method contrasts with those of Helbing, Johansson, and Al-Abideen, Yanagisawa et al., and Schadschneider, Debashish, and Nishinari, whose findings suggest individual decision making can help with safe egress.

It is important to note that the data obtained and analyzed by the researchers discussed above and used in this thesis is the result of research and development. Their work presents innovative ideas to create a safe environment for the public at venues. The researchers discussed in this literature review have not disregarded necessary fire ordinances and safety. In their work, these researchers were following the ordinances

57 Matson, "Strategically Placed Obstacle."

58 Muir and Marrison, "Human Factors."

59 Ibid.

60 Ibid.

required by fire marshals, who require adherence to the National Fire Protection Association's (NFPA) Life Safety Code 101 in the United States.[61] European countries currently use international building codes developed from U.S. codes and ordinances to comply with life safety as well.[62] The codes define and describe how fire departments must protect assemblies of individuals, both indoors and out.[63] The researchers highlighted in this thesis use this information in conjunction with their theories to develop new and better ways to facilitate egress from crowded venues and to provide safety for citizens.

2. Literature Review Conclusion

This literature review shows the many moving parts related to crowd dynamics and public safety at events. Also, the review shows how most authors in the review believe that crowd decisions are major contributors for public safety. There are many researchers working to develop answers to the problems associated with large crowd exiting at outside venues. Still, Helbing, Anders, and Zein pose similar opinions regarding the dangers of densely populated crowds. Some researchers advocate the use of software to determine safety at venues while others believe that placing obstacles at exits will enhance the ability of a person to make decisions in an emergency. All the researchers discussed in the literature review are dedicated to determining the safest means for people to consistently exit venues, buildings, and structures without harm. In California, fire departments are responsible for using the information established by experience and research to provide safety for the public at public venues and in the areas they serve.

D. RESEARCH DESIGN

This thesis asks how emergency personnel can plan for the safety and care of dynamic crowds during outdoor events. Incidents at crowded venues resulting in injury can

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61 National Fire Protection Association, "NFPA 101."

62 George H. Potter, "International Fire Safety Legislation: An Overview," *Fire Engineering*, February 14, 2008, http://www.fireengineering.com/articles/2008/02/international-fire-safety-legislation-an-overview.html.

63 *Fire and Life Safety Planning and Management Guide for Public Assembly Events*, University of Maryland, accessed April 29, 2017, https://www.essr.umd.edu/sites/essr.umd.edu/files/files/documents/pubguide.pdf.

be the result of emergencies and overcrowding. The literature indicates that crowds typically respond to emergencies by looking for safe exits, not by running in a state of panic.[64] It is essential for fire department to identify the factors contributing to deaths and injuries at crowded events, so that fire departments may consider these factors for their operations and response.

The first step of the research is to understand how crowds move and what determines their movement. This thesis also examines strategies for crowd management to prevent injuries and deliver care. The information comes from open sources, including sources such as after action reports, journals, newspaper articles, and reports of boards of inquiry; however, sources are limited to historical public events since practical experimentation of actual crowd conditions may not be safely replicated in a research scenario. The next step is identification and analysis of common problems responders encounter in trying to deliver aid and care at large events.

For the third step, this researcher conducted case study analysis to examine crowd behavior and response issues together. The four case studies include the 1989 Hillsborough soccer match, the 2011 Reno Air Race, the 2013 Boston Marathon bombing, and the 2014 Travis Air Force Base (AFB) air show, all of which include tragic events and have government, open source material available for analysis. This research uses root cause analysis in the case studies to identify causal factors leading to deaths and injuries.[65] Using Department of Energy guidance on the procedure for root cause determination, the first phase in determining root cause is to identify the specific problem and not the unintended occurrence that resulted. The second phase is to determine the importance of the incident with regard to injuries that happen at the events and what may have caused them. The third phase is to identify the cause of the incident by examining the pre-event risk assessment.

64 Christopher Cocking and John Drury, "The Mass Psychology of Disasters and Emergency Evacuations: A Research Report and Implications for the Fire and Rescue Service," *Fire Safety, Technology and Management*, 10 (2008): 13–19.

65 U.S. Department of Energy, *Root Cause Analysis Guidance Document* (DOE-NE-STD-1004-92) (Washington, DC: U.S. Department of Energy, 1992), https://www.standards.doe.gov/standards-documents/1000/1104-std-1992/@@images/file.

The last phase is to find the cause by starting at the end of the incident and working backward toward the beginning to determine what factors may have caused the incident.[66]

With the objective of identifying preventive measures for future incidents, this thesis uses the root cause analysis developed from case studies to craft recommendations for planning events at outside venues. However, this research has some limitations since there is little information specific to fire departments at crowded venues. Additionally, the study does not include crowd control issues that are mitigated by law enforcement response. However, because law enforcement is a component of a unified command, this thesis addresses operability. This project is limited also by the amount of open source information available related to historical incidents.

E. CHAPTER OUTLINE

Chapter II discusses several incidents and the issues surrounding the loss of life and injury. Chapter III looks at safe egress and fire department involvement by methods of response at large venues. Chapter IV examines four case studies involving patrons at outside venues who sustained severe injuries. Chapter V combines the data collected and provides a guide that can be used to organize future events to decrease the possibility of injury. Finally, Chapter VI concludes with a synopsis of the analysis and collected data by developing information from researchers discussed in the literature review and their findings.

[66] Ibid., 1.

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II. CROWD BEHAVIOR

People form groups, change direction, and become a vulnerable population at concerts, sporting events, and religious gatherings. The probability of death and injury at such events increases with the size of the crowd and frequency with which they gather. This chapter focuses on the safety and care for groups of people forming at outside venues during races, golf tournaments, air shows, holidays, sporting events, and other similar gatherings. This chapter presents example descriptions of recent events and emergency response. The word *behavior* is generally used to describe how people move and react at large outdoor events.

A. CROWD DYNAMICS

Crowd dynamics is the study of people forming into groups and the ways they move safely.[67] The different makeup of crowds adds to the difficulty of their movement.[68] People are not all the same and do not move with the same gait, and this affects their ability to move through a crowd. Some of the contributing factors can be height, weight, age, wheelchairs, and strollers; crowd movement can also be affected by those who move against the flow of traffic to make purchases, find friends, or look for a better vantage point.

As previously discussed, the density of a crowd is one determinant in how safely crowds move. One person per square meter is preferred at venues, according to Helbing, Johansson, and Al-Abideen.[69] Proper spacing allows people to change direction quickly and move at their individual paces. As the number of individuals per square meter increases, their ability to move freely decreases, multiplying their possibility of risk of an incident. Once the density reaches six people per square meter, the risk of an incident reaches a critical point. At that point, the density is so high that if one person falls or stumbles, an injury will likely occur.[70] The study of crowd density is complicated and relies

[67] Still, “Crowd Dynamics: Thesis,” 5.

[68] Ibid., 24.

[69] Helbing, Johansson, and Al-Abideen, “The Dynamics of Crowd Disasters.”

[70] Ibid.

on many factors, including the demographics of the crowd. Therefore, people who conduct research on crowd movement must consider all factors to be able to predict movement and responses.

Physicists conducted research on crowd movement in 1995 using particle models consisting of small circular beads to mimic the movement of people.[71] The models revealed an interesting phenomenon, showing how people move like fluid and are trapped or slowed by narrowed passages, obstacles, direction change, or stopping. Speed and direction change in dense crowds can be lethal. The studies have found inadvertent slowing or stopping causes a rebound effect that immediately turns into a wave-type response.[72] Energy increases as pressure from moving bodies are exerted on members of the crowd, causing injury and death.[73] As each person moves forward, the people near him or her do the same, each forward movement becoming successively closer and closer. The result is a densely packed crowd that is potentially deadly.[74] Crowd movement happens so quickly that it resembles ripples on a pond from a cast stone. John Fruin cites examples of crowds in which people have experienced injury and death from sudden shifts or violent actions with densities of only seven people per square meter.[75] Sudden movements may lift people into the air as high as 10 feet, removing their shoes and clothes, and leaving them on the ground unable to move due to crowd movement or their own anxiety.[76] As the crowd moves over the victims, they are unable to breathe due to compressive asphyxia (being crushed), which can result in injury or death.[77]

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[71] Ibid.

[72] Ibid.

[73] Wenjian Yu and Anders Johansson, "Modeling Crowd Turbulence by Many-Particle Simulations," *Physical Review E* 76, no. 4 (2007), https://doi.org/10.1103/PhysRevE.76.046105.

[74] John J. Fruin, "The Causes and Prevention of Crowd Disasters" (presented at First International Conference on Engineering for Crowd Safety, London, England, March 1993), http://crowdsafe.com/fruincauses.pdf. Revised for crowdsafe.com, January 2002.

[75] Ibid.

[76] Ibid.

[77] Ibid.

B. CROWDS: HIGH RISK, LOW FREQUENCY

The following examples of incidents illustrate the problems associated with crowd density at several types of venues and are arranged chronologically. At crowded events, fire departments are responsible for injury prevention and mitigation. Therefore, knowing the type of incidents that have occurred may provide firefighters with needed information for prevention of incidents at future events. Additionally, investigation and after action reports provide data that must be analyzed to determine if the information obtained is applicable and useful for prevention or code changes.

Although large outside venues are common, they occur less frequently than daily human traffic in urban, suburban, and rural areas, which have little threat of crowd surge. However, large congregations of individuals have led problems. Dense crowds are found at venues all over the world, and in crowds, social economic status is irrelevant. Historically, the number of deaths continues to rise from the same type of tragedy regardless of information published on tragedies at related events. For example, there was a tragic loss of life on the opening day of the newly constructed Brooklyn Bridge. The last child of the Roebling family, Emily, supervised the completion of the bridge in 1883. She was the first person to walk across the bridge alone during the opening ceremony. After she crossed the bridge, 1,600 people followed to observe the engineering marvel that had taken 15 years to complete. As the crowd walked across the bridge, people stopped to sight see the river and New York. The crowd compressed as it stopped, and people were unable to move forward. Additionally, the densely packed crowd reacted when people mistakenly yelled out that the bridge was collapsing. Their rush to gain safety caused people to be crushed; 12 people were killed, and hundreds of others were injured[78] (see Figure 1).

[78] Robert McNamara, "Brooklyn Bridge Disaster: Soon after Bridge's Opening, a Panicked Crowd Turned Deadly," ThoughtCo., last updated March 3, 2017, https://www.thoughtco.com/brooklyn-bridge-disaster-1773696.

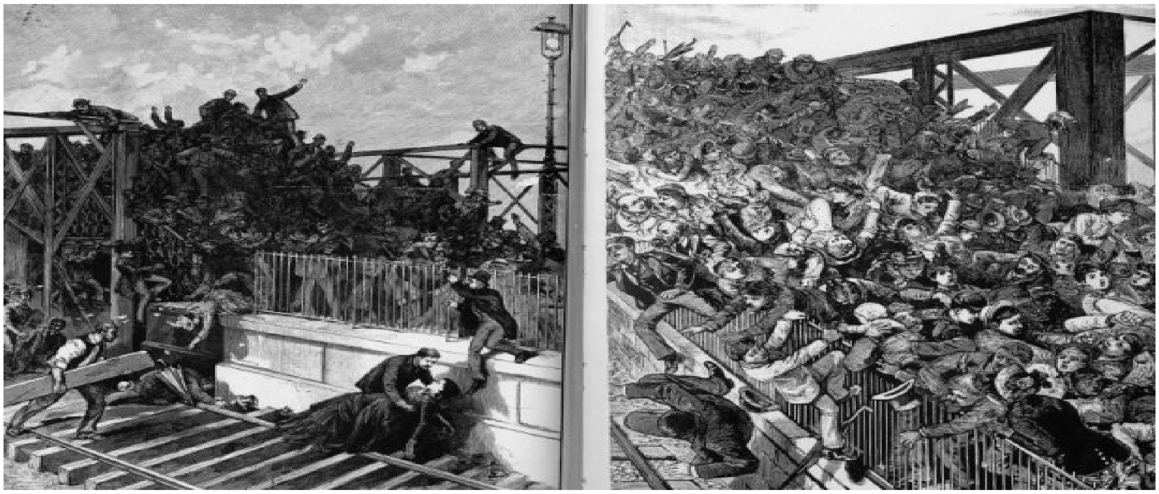

Figure 1. Illustrations of the Brooklyn Bridge Incident[79]

More than a century after the Brooklyn Bridge incident, crowd accidents continue to happen and not just in the United States. On July 3, 1990, a tragedy occurred in a large crowd in Mina, Saudi Arabia during the pilgrimage to Mecca.[80] Thousands sought safe refuge from the 112-degree heat in an air conditioned tunnel. As many as 1,400 people were killed in what was described as a stampede in the tunnel leading to Mecca.[81] Some of the witnesses indicated that when people entered the tunnel, the crowd stopped moving for an unknown reason, and people succumbed to unconsciousness from asphyxiation. The capacity of the tunnel structure was 1,000 people; however, according to witnesses, the crown in the tunnel grew to more than 5,000 people during the incident[82]

[79] Sources: "The Desperate Struggle for Life," drawing by staff artist at Frank Leslie's *Illustrated Newspaper*, June 21, 2016, http://www.brownstoner.com/history/Brooklyn-bridge-death-stampede-tragedy-1883/; Lady G, "Panic on the Brooklyn Bridge!," *The Realm Of Olde Brooklyn* [blog], March 21, 2012, https://therealmofoldebrooklyn.wordpress.com/2012/03/20/panic-on-the-brooklyn-bridge/.

[80] Nidal al-Mughrabi, "More Than 700 Pilgrims Die in Crush in Worst Haj Disaster for 25 Years," Reuters, September 24, 2015, http://www.reuters.com/article/us-saudi-haj-casualties-idUSKCN0RO0RN20150924.

[81] Ibid.

[82] "Saudi Arabia Hajj Disaster Death Toll Rises," *Aljazeera America*, October 19, 2015, http://america.aljazeera.com/articles/2015/10/19/hajj-disaster-death-toll-over-two-thousand.html.

Crowd related tragedies during the Hajj resulting in death and injuries are frequent due to crowd crush. Almost 10,000 pilgrims have been killed at the Hajj since 1985.[83] In an incident in October 19, 2015, more than 2,000 died in what has been described as a stampede in Mina near a ritual stoning bridge.[84] Although this tragic event was not sparked by excessive heat as it was during the pilgrimage in 1990, it had similar devastating consequences. As with the 1990 incident, this incident was the result of too many people packed densely in a relatively small space.[85]

The incident at Mina, like other similar venues, caused injury and death due to the high number of individuals per square meter as people tried to move.[86] The incident is a prime example of an overly dense group, which because of its high density, prevented free movement of people.[87] At the event, many people complained about the narrow pathways restricting the flow of traffic. As the pilgrims tried to move to the stoning bridge, several stumbled and were unable to get up due to the massive number of individuals on top of and around them; the crowd was too dense. Furthermore, railings bent from the weight of the crowd and were pushed on top of people already on the ground, preventing them from gaining safety.[88] Helbing, Johansson, and Al-Abideen state that as many as 10 people per meter are not unusual at the Hajj, supporting the claims of research that over density of crowds at events like the Hajj is dangerous.[89]

Famous musicians draw also huge crowds. The grunge rock band Pearl Jam was one of the many performing at the four-day Roskilde Festival in Denmark in July 2000. The festival was started in 1971 to emulate Woodstock.[90] At the festival that year, there

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[83] Ibid.

[84] Ibid.

[85] Helbing, Johansson, and Al-Abideen, "The Dynamics of Crowd Disasters."

[86] G. Keith Still, "Static Crowd Density 1," GKStill," last updated May 3 2013, http://www.gkstill.com/Support/crowd-density/100sm/Density1.html.

[87] Helbing, Johansson, and Al-Abideen, "The Dynamics of Crowd Disasters."

[88] iPhone 2015, "What Actually Happened in 2015 Mina Stampede? Real Footage 1:17," YouTube, October 4, 2015, https://www.youtube.com/watch?v=_25CD37png4.

[89] Helbing, Johansson, and Al-Abideen, "The Dynamics of Crowd Disasters."

[90] Associated Press, "8 Crushed to Death at Rock Festival in Denmark," *The New York Times*, July 1, 2000, http://www.nytimes.com/2000/07/01/world/8-crushed-to-death-at-rock-festival-in-denmark.html.

were seven stages arranged to provide continuous entertainment for the 100,000 fans in attendance. Fans pushed to get a closer view at the stage they were at as entertainment started.[91] Pearl Jam band members recognized the impending tragedy, and using the public address system, they began instructing the fans to move back three steps. Witnesses complained that patrons were continually pushing their way toward the stages, preventing people in front from moving. As people stumbled and fell, others fell on top of them creating a human pile; nine were killed many others were injured. Pearl Jam members walked off the stage when they learned of the severity of injuries that happened in front of them. When the band left the stage, fans moved back and exposed those who were killed in the crowd rush.[92]

Other festivals have drawn even larger crowds than were at Roskilde. The Love Parade was a one-day festival, primarily celebrating music. It started out in Berlin in 1989 and later moved to Duisburg, Germany.[93] The festival has continually grown in popularity each year. More and more people flocked to the listen to music at the events, until 2010 when an estimated 500,000–1,000,000 people arrived.[94] The crowd was so large that 1,500 police at the event quickly reported they were unable to control the crowd.[95] Simple math puts the ratio of festival patrons to police officers at 666 to 1. An incident occurred in an underpass that exceeded its capacity (see Figures 2 and 3). People stopped moving as others were trying to move toward the underpass. A crowd crush occurred as the density of people increased and were unable to move.

That year at the Love Parade, more than 300 people were injured, and 19 died of traumatic asphyxia.[96] The mayor of Duisburg quickly declared a state of emergency in the city, asking for help from rescue workers. There were so many people distributed over a

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[91] Ibid.

[92] Ibid.

[93] "19 Dead in Love Parade Stampede," *The Telegraph*, July 24, 2010, http://www.telegraph.co.uk/news/worldnews/europe/germany/7908522/19-dead-in-Love-Parade-stampede.html.

[94] Ibid.

[95] Ibid.

[96] Ibid.

large area that the festival continued, and people were unaware of police and ambulance sirens as rescue workers arrived to tend to the injured at the scene of the accident.[97]

Figure 2. Tunnel Where the Crowd Crush Took Place[98]

[97] Ibid.

[98] Source: “The Love Parade Music Festival from a Gathering of Just 150 to More Than 1 Million Revellers.” *Metro News*, July 25, 2010, http://metro.co.uk/2010/07/25/love-parade-a-festival-which-celebrated-peace-and-love-466699/.

Figure 3. Love Parade Crowd Crush[99]

The resultant catastrophic event is similarly described by Helbing, Johansson, and Al-Abideen, who see a crowd much like moving water. Once the density reaches six persons per meter, it is impossible for the number of people entering an area to match the number of people leaving the same area, and this creates an incident.[100] Regardless of crowd density, people never stop moving, which also increases their chance of injury significantly as the events above illustrate.[101]

C. CROWD RESPONSES TO NATURAL EVENTS: WEATHER, ACCIDENTS, AND EARTHQUAKES

Sudden incidents evolving from the unexpected inclement weather, accidents, and earthquakes can be just as lethal and are often more dangerous than incidents created by humans. People often disregard warnings for their safety to pursue personal interests and entertainment, which can result in their death and injury. This chapter describes naturally

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[99] Source: Uwe Weber, "World Press Photo of the Year 2010," Zeitraster, accessed October 15, 2017, www.zeitraster.de/awards/.

[100] Helbing, Johansson, and Al-Abideen, "The Dynamics of Crowd Disasters."

[101] Ibid.

occurring phenomena and accidents illustrating public response to several events, some deadly. One would anticipate that once the people become aware of a threat, an expected appropriate response would be for them to seek safety. However, people do not always respond as expected.

1. Weather

The high risk of natural phenomena and accidents create deadly problems for unsuspecting crowds and participants at outside venues. Public safety and organizers who are in charge of an outdoor venue have a responsibility to continually watch weather forecasts and ensure the safety of their equipment, thus preventing the possibility of injury to patrons. Part of the responsibility is to remove, disassemble, or close equipment that may pose a hazard during inclement weather.

While heat is an issue for people who are not prepared, cold weather is equally as dangerous. The Spartan race is an annual event in the Sacramento area and is also held at many locations across the United States.[102] It is one of the most arduous and grueling obstacle course races available for amateur and professional athletes. The 13-mile course takes runners through 35 spectacular obstacles in different terrain and elevations to challenge their endurance and strength.[103] The Sacramento 2012 race was held in November, and over 4,000 athletes had to contend with low temperatures. Midway through the race, one of the obstacles runners encountered was a pool of ice water. The participants were required to swim underwater for a specified distance before continuing the race. Rain, wind, and mud compounded the problems associated with the cold-water swim. As a result of the swim, 30 participants had to be treated for hypothermia, and they were transported to the hospital.[104]

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[102] "The Spartan Race Types," Spartan Race, accessed September 5, 2017, https://www.spartan.com/en/race/learn-more/race-types-overview.

[103] Ibid.

[104] "Cold, Wet Weather Sends Several Spartan Race Participants to Hospital," *CBS Channel 13 News*, November 17, 2012, http://sacramento.cbslocal.com/2012/11/17/spartan-race-sends-several-to-hospital-with-possible-hypothermia/.

Though it was rain instead of temperature this time, the weather was responsible for a crowd rush resulting in injuries and fatalities at a concert in Minsk, Belarus in 1999. A sudden cloudburst and hail prompted more than 1,000 concertgoers to seek shelter under an overpass.[105] The rush of the crowd caused people to move so quickly and uncontrollably that a 19-year-old fan named Vitaly Milentyev said he was an unable to walk to safety.[106] Just as Fruin's research has indicated, this person was physically moved along by the crowd.[107] Milentyev said he was propelled by the crowd as it moved under the structure and could do nothing. He attempted to save a young woman from being crushed by the crowd but was unsuccessful.[108] The result of the crowd's sudden movement caused 54 deaths, including the death of two police officers who were trying to control the fans. There were also 150 injuries, 37 of which were critical. [109]

2. Accidents

Weather is certainly an issue and creates deadly consequences as indicated previously. However, dangerous consequences can happen for most any reason at crowded events. Turin, Italy was a recent location where members of a large crowd fell victim to a catastrophic accident. In June 2017, thousands arrived to watch a soccer match between Italy's Juventus and Spain's Real Madrid.[110] The match was held in Cardiff, Wales; however, people wanted to see the game locally. To accommodate, city officials the in Turin provided a giant TV screen in Piazza San Carlo for people to watch the match[111] (see Figure 4). Although very dense, the crowd appeared to be stable in the plaza. Initially, in

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[105] Phil Reeves, "Pop Fan's Stampede Crushes 54 to Death in Minsk Metro," *The Independent*, May 31, 1999, http://www.independent.co.uk/news/pop-fans-stampede-crushes-54-to-death-in-minsk-metro-1097439.html.

[106] Ibid.

[107] Fruin, "The Causes and Prevention of Crowd Disasters."

[108] Reeves, "Pop Fan's Stampede."

[109] Ibid.

[110] James Reynolds, "Turin Stampede: '1,500 Injured' at Juventus Screening," *BBC News*, June 4, 2017, http://www.bbc.com/news/world-europe-40147813, sec. Europe.

[111] Associated Press, "Fans Involved in Near-Stampede in Turin after Champions League Final," Sports Net, June 3, 2017, http://www.sportsnet.ca/soccer/fans-involved-near-stampede-turin-champions-league-final/.

the piazza, there was no crowd rush in which throngs of people densely packed were attempting to move.[112]

Figure 4. Turin, Italy: Fans Watching Soccer Match[113]

While fans were enjoying the match, someone reportedly set off a firecracker, and the response was devastating as patrons believed there had been a gunshot or bomb had exploded.[114] Unfortunately, the sound created a rush of individuals surging in all directions trying to seek safety. The *BBC* produced a striking video that shows what happened as the crowd heard the noise.[115] Much like a rock thrown into a pond, a ripple effect of surging people overwhelmed those standing near them, knocking them to the ground. Turin Deputy Mayor Renato Saccone dismissed the incident as panic, but thousands of fans were so densely packed, they could hardly move.[116] This surge of people in response to the

112 Helbing, Johansson, and Al-Abideen, "The Dynamics of Crowd Disasters."

113 Source: Associated Press, "Fans Involved in Near-stampede in Turin after Champions League Final," SportsNet, June 3, 2017, http://www.sportsnet.ca/soccer/fans-involved-near-stampede-turin-champions-league-final/. Photo by Alessandro Di Marco.

114 Reynolds, "Turin Stampede."

115 Ibid.

116 Ed Adamczyk, "1,500 Injured in Soccer Crowd Stampede in Turin, Italy," *UPI World News*, June 5, 2017, http://www.upi.com/Top_News/World-News/2017/06/05/1500-injured-in-soccer-crowd-stampede-in-Italy/7821496659323/.

firecracker noise resulted in injuring more than 1,500 people in an instant.[117] Hundreds of shoes were torn from the fans' feet as the crowd rush happened. Parents and children were separated and initially unable to find one another.[118]

3. Earthquake

In contrast to the crowd crush incident at Turin, a Bay Area earthquake brought a different response at Candlestick Park Stadium in 1989. The World Series was held in San Francisco and dubbed the "Battle of the Bay." The Oakland A's and San Francisco Giants hosted a packed stadium with thousands of fans for game three of the series.[119] Before the first pitch was thrown, a massive 6.9 earthquake hit the Bay Area.[120] Footage and photos captured the historical tragedy on almost every live sports show. When the earthquake erupted, the fans began running toward the baseball field as they were called out by the players; they used the field as an area of safe refuge.[121] In anticipation of injuries, police and ambulance crews also drove onto the field. Although people were frightened, there was no sign of crowd rush or injury from the fans trying to get to the field; some stayed in their seats, afraid to move.[122] There was no available information as to the reason for the fans remained unharmed in this incident. Perhaps it was due to the large area of safety provided by the baseball field and the ability of the crowd to remain calm. Or possibly the high concentration of fans moving to the sparsely populated baseball field, which held a low concentration of people. Unfortunately, 63 people were killed and more than 3,000 were

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117 Ibid.

118 Reynolds, "Turin Stampede."

119 *The Day the Series Stopped*, directed by Ryan Fleck (2014, ESPN 30 for 30), accessed July 16, 2017, http://www.espn.com/30for30/film?page=thedaytheseriesstopped.

120 Chris Bahr, "Flashback: Massive Earthquake Interrupts 1989 World Series," *Fox Sports*, October 17, 2015, http://www.foxsports.com/mlb/story/san-francisco-giants-oakland-athletics-world-series-earthquake-bay-area-candlestick-park-101715.

121 Ibid.

122 Jerome Holtzman, "Earthquake Puts Series on Hold," *Chicago Tribune*," October 18, 1989, http://articles.chicagotribune.com/1989-10-18/sports/8901230446_1_bay-bridge-oakland-alameda-county-coliseum-fans.

injured as they tried to escape the damage from the from the 6.9 earthquake in the surrounding cities of San Francisco and Oakland.[123]

4. Crowd Response to Terrorist Action

Manchester, United Kingdom was a recent site of multiple injuries and fatalities at a May 2017 Ariana Grande concert. The live concert at the Manchester Arena was part of her international music tour.[124] As the performance was ending, and thousands of young fans began leaving the arena, an explosion rocked the building. In a foyer outside the front doors, a bomb killed 22 people, including the bomber, and injured almost 60 people.[125] The concert-goers made their way to exits to escape possible injury. People were taken to eight area hospitals reportedly seeing metal nuts, used as shrapnel to increase the number of injuries, on the floor of the foyer.[126] The fans at the concert did not initially know there was an attack, necessitating security to broadcast the incident. Witnesses report some fans pushing children and a person in a wheelchair aside so they could exit.

Police, fire, and EMS arrived to manage the scene with thousands of patrons that initially filled the Manchester arena and to provide care and transport for the injured fans. Video provided by the media of the mitigation of the scene focused on the front of the community center, leading to the assumption that it was the only exit in use.[127] Additionally, the media has provided some film clips of people running to the front exits directed by security. It is unknown whether people used the side or rear exits to leave the building more quickly.

[123] "The 1989 Loma Prieta Earthquake in Numbers," *ABC10 News*, October 17, 2016, http://www.abc10.com/news/local/california/the-1989-loma-prieta-earthquake-in-numbers/337049945.

[124] Rory Smith and Sewell Chan, "Ariana Grande Manchester Concert Ends in Explosion, Panic and Death," *New York Times*, May 22, 2017, https://www.nytimes.com/2017/05/22/world/europe/ariana-grande-manchester-police.html.

[125] Holtzman, "Earthquake Puts Series on Hold."

[126] Smith and Chan, "Ariana Grande Manchester."

[127] *ABC News*, "Ariana Grande Concert Explosion at Manchester: At Least 19 Dead in Attack," YouTube, May 22, 2017, https://www.youtube.com/watch?v=FAXwJT-jF94.

Britain fell victim to another terrorist attack on June 3, 2017 on the London Bridge and at Borough Market.[128] People were walking across the bridge and toward Borough Market on Saturday evening when three people in a van ran down several tourists. The three suspects got out of the van and began stabbing people as they ran toward the market area. Eight people were either run down by a vehicle or stabbed to death, while scores of others were injured. The Islamic State group took responsibility for the attack as they shouted, "This is for Allah."[129] Tourists began fighting back during the terrorist attack. For example, Ignacio Echeverria attempted to stop a terrorist from stabbing a woman on the bridge.[130] He was joined by several others who also tried to fight off the attackers while waiting for police response.[131] A baker, off-duty policeman, banker, and other citizens put their lives in danger at the marketplace while waiting for help to arrive.[132] The circumstances in this incident are different from other instances in this chapter. For one, it took place in two distinct areas, starting at the bridge and traveling to the market place. Also, the attacked venues had relatively few citizens compared to large crowds at planned events. However, the streets, tables, and chairs that lined the market place created barriers and bottlenecks, slowing the crowd's ability to exit. People did run to find safety, but they also had the presence of mind to help others in a life-threatening situation. Panic is not always people's response in an emergency. People can make sound decisions to help themselves and others.[133]

D. CONCLUSION

Chapter II discussed how people gather at venues for pleasure, entertainment, and worship. Unfortunately, the events can draw large crowds and people are unable to effectively move to safety. As crowds move like fluid, as described by Helbing, Johansson,

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[128] "London Attack: What We Know So Far," *BBC News*, June 12, 2017, http://www.bbc.com/news/uk-england-london-40147164.

[129] Ibid.

[130] Ibid.

[131] Ibid.

[132] "London Attack: Romanian Baker and Spanish Banker among Heroes," *BBC News*, June 8, 2017, http://www.bbc.com/news/uk-40149836.

[133] Fahy, Proulx, and Aiman, "'Panic' and Human Behaviour."

and Al-Abideen, they become hampered by individual decisions and bottlenecks in areas that slow the leading edge of crowds, and this can cause injury and death.[134] The unfortunate phenomenon of crowd movement has created problems for emergency services trying to prevent injury at large events. It is often difficult to navigate through a crowd and can become dangerous for the responders as well. This was illustrated by the example of the concert in Minsk, Belarus when two police officers were accidentally killed while trying to control a crowd rushing to find shelter from an unexpected hail storm during a concert.

The research has examined outdoor events to compare people's responses to emergencies and the resulting injuries. The data collected will help determine how fire departments can provide consistent planning, support, and care at events. The findings may also contribute to a cohesive working atmosphere for all emergency services by collaboratively sharing information and working together. Sharing data can produce lessons learned and best practices that may prove helpful for future events.

The next chapter discusses issues related to fire departments and their ability to provide appropriate staffing and equipment. In addition, the chapter explores response to incidents and the relative time needed to arrive to a scene. Risk is discussed as it applies to events to prevent incidents from occurring. The goal is to provide safety for the public.

[134] Helbing, Johansson, and Al-Abideen, "The Dynamics of Crowd Disasters."

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III. FIRE DEPARTMENT FRAMEWORK

Circus master P.T. Barnum was not the first person to recognize the importance of moving people safely to an exit. However, he was innovative in the way he moved hordes of people who jammed into his tents to see the wonders of his circus. Barnum's marketing acumen led him to remove the exit signs and install signs that read "This way to the Egress" to prevent people from staying too long at exhibts and preventing others from seeing the attractions.[135] Not knowing the definition of the word egress, the crowds moved through the "egress" doors as they closed and locked behind them, preventing their return. Barnum had found a way to move people efficiently and safely. [136]

Scientists and engineers have tried to achieve what Barnum did both inside buildings and at outside venues for many years. The professionals' primary goal is safe, expedient entry and exiting for employees and patrons so as to prevent incidents. Early in the twentieth century, there were several tragedies due to fires and lack of adequate exiting.[137] The loss of life prompted fire and building officials to change fire codes and ordinances to protect people.[138] Over a hundred years later, safety research continues. This chapter looks at some of the fundamental considerations for developing a safe atmosphere for patrons at large venues. A complete safety plan cannot be developed without knowing capabilities and probablities in advance as well as by looking at historical events.

A. ASSESSING RISK

Determining risk before an event or during an incident requires some deductive reasoning by reverse engineering. While planning for an event, fire departments must bring all interested parties to the table and ask questions about the scope of work and services

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[135] "Welcome to the Egress," P. T. Barnum, accessed July 31, 2017, http://www.ptbarnum.org/egress.html.

[136] Barnum.

[137] Daniel Byrne, "After 100 Years: The Lesson to Be Learned from Triangle Shirtwaist," Firehouse, March 18, 2011, http://www.firehouse.com/article/10463244/triangle-shirtwaist-fire-lessons-in-fire-codes-and-prevention.

[138] Ibid.

they are to provide. Understanding the event and the equipment that will be used gives fire departments a starting point to look for possible safety threats. As Vose suggests, inspectors must allow the required work to drive the needs for the assessment, rather than allowing the assessment to drive the need.[139] Additionally, it is important for fire departments to ask the organizers about suspected problems that may occur involving individuals or groups at the planned venue.[140] When planning for a large event, there are several things for fire departments to consider, including fire safety, law enforcement, logistics for equipment, crowd numbers, and weather. It is important to understand what risks are involved before attempting to determine the event's value.

Risk is the possibility of an unplanned event happening, causing danger and/or injury. Should the risk occur, it is unfavorable for the participants at the venue.[141] The risk investigators' responsibility is to look for gaps, problems, and possibility of failure. Moreover, the risk investigators must evaluate the sources of the problems to determine the impact the deficiency. Lastly, investigators must be vigilant in their approach to identify and mitigate known risks to provide safety for the venue.

Assessing risk can also prevent new incidents from occurring at an event that is already in progress, which allows the operation to progress more smoothly. There are many things that can decrease risk at a venue and increase safety. Some of the possibilities are:

- Provide specific lanes for supply vehicles and emergency equipment apart from the crowd location for safety.[142]
- Look for electrical, plumbing, and environmental concerns.[143]
- Determine the type of barriers needed to prevent injury and allow safe exit or entry.
- Designate areas for cooking and related equipment to prevent the possibility of fire and safety hazards.

139 Vose, *Risk Analysis*.

140 Health and Safety Executive, *Managing Crowds Safely: A Guide for Organiser at Events and Venues*, 2nd ed. (Surrey, UK: Crown, 1996), http://www.hse.gov.uk/pUbns/priced/hsg154.pdf.

141 Vose, *Risk Analysis*, 3.

142 Health and Safety Executive, *Managing Crowds Safely*, 18.

143 Ibid., 44.

- Continually check the weather and be prepared for wind, rain, or thunderstorms at outside venues.[144]
- Ensure professionalism, credentialing, and training of those who are involved in the program and their employees.
- Secure the incident command post from unauthorized entry.

Fire department evaluators must maintain and continually update lists from previous risk assessments indicating areas of possible deficiency. Retaining such lists provides a reference for future venue inspections. The information collected may also indicate trends for future ordinance or safety code changes. The importance of properly executed risk assessments is paramount since they pertain to public safety.

Risk assessments must also account for people. For example, firefighters conducting a risk assessment must consider the demographics of the individuals those who are involved in an incident or attending the venue.[145] The individuals may be predominately young, like those at the Arianna Grande concert in Manchester, and in need of the assistance of adults.[146] Alternatively, the venue may be a mixture of ages with some needing assistance with wheelchairs, walkers, or strollers. The assessment should include safe exit paths for individuals who can walk on their own and alternative means for those with disabilities. Fire department planners must anticipate problems before allowing a venue to open that could result in injury the public. Therefore, a risk assessment is paramount to determine the level of safety required at a given event. It should also include the degree of risk the venue organizers are willing to accept during the event.

B. STAFFING STANDARDS AND RATINGS

Fire departments have guidelines for their capabilities and response to serve the public. The National fire Protection Association (NFPA) and the Insurance Services Office (ISO) are organizations that establish standards for the number of firefighters and

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[144] Ibid., 7.

[145] Ibid., 50.

[146] "Manchester Attack: Mental Health Support after Arena Blast," *BBC News*, July 31, 2017, http://www.bbc.com/news/uk-england-manchester-40773540.

equipment responding to a given type of emergency.[147] Working in concert, NFPA and ISO also provide standards for municipality water system infrastructure to combat fires.[148] NFPA alone is responsible for producing more than 300 codes that cover firefighters and equipment requirements.[149] The codes are for all aspects of building and life safety. For example, NFPA 1710 provides information for the deployment of professional firefighters (paid) going to emergencies. The standard covers fire, EMS, wildland, airports, water, and other problems encountered by firefighters.[150] Similarly, NFPA 1720 covers the same situations for volunteer fire (unpaid) agencies.

Both professional and volunteer agencies are held to a strict standard requiring the shortest average response time to an emergency and to ensuring public safety. As it is unable to publish information for every conceivable type of emergency, NFPA has produced several general response scenarios and provided standard acceptable response times. The national standards establish safety for people, property, and animals. For example, NFPA 1720 indicates standard response times for volunteer firefighters responding to a 2,000 square-foot (sq.-ft.) home on fire.[151] Table 1 is an example of typical response standards to help the reader understand basic operations since NFPA does not develop standards specifically for outdoor venues. It is important also to note that for those occurrences and emergencies that may unforeseen, the authority having jurisdiction (AHJ)

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[147] "Fire Suppression Rating Schedule (FSRS) Overview," ISO Mitigation, 2017, https://www.isomitigation.com/fsrs/fire-suppression-rating-schedule-fsrs-overview.html.

[148] National Fire Protection Association, "List of NFPA Codes and Standards," accessed October 15, 2017, http://www.nfpa.org/Codes-and-Standards/All-Codes-and-Standards/List-of-Codes-and-Standards.

[149] Ibid.

[150] National Fire Protection Association, *Implementation Guide* (NFPA 1710), 2nd ed. (Washington, DC: International Association of Fire Fighters, 2002), http://www.cpf.org/go/cpf/?LinkServID=3EAD2730-E0C3-218B-07A8D711F8AFF5E0&showMeta=0.

[151] National Fire Protection Association, "NFPA 1720: Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Volunteer Fire Departments," 2010, http://www.nfpa.org/codes-and-standards/archived/safer-act-grant/nfpa-1720.

determines the response capabilities.[152] Outside venues would fall under special risks in Table 1,[153] and the responsibility of the decision falls on the AHJ.[154]

Table 1. 4.4.2 NFPA 1720 Volunteer Firefighter Response (2000 sq. ft. Home)[155]

Demand Zone[a]	**Demographics**	**Minimum Staff to Respond[b]**	**Response Time (minutes)[c]**	**Meets Objective (%)**
Urban area	>1000 people/mi2	15	9	90
Suburban area	500–1000 people/mi^2	10	10	80
Rural area	<500 people/mi^2	6	14	80
Remote area	Travel distance ≥ eight mi	4	Directly dependent on travel distance	90
Special risks	Determined by AHJ	Determined by AHJ based on risk	Determined by AHJ	90

[an] A jurisdiction can have more than one demand zone.

[b] Minimum staffing includes members responding from the AHJs department and automatic aid

[c] Response time begins upon completion of the dispatch notification and ends at the time interval shown in the table.

The ISO uses a rating system that scores fire departments depending on whether their firefighters are paid professionals or volunteers.[156] The Fire Suppression Rating Schedule uses four different categories to establish an ISO score.[157] ISO and fire departments use it to measure the emergency mitigation capability of departments for the areas they serve. Departments achieve a rating by having emergency communications, an

152 Ibid.

153 Ibid.

154 Ibid.

155 Source: National Fire Protection Association, "NFPA 1720."

156 "Fire Suppression Rating Schedule," ISO Mitigation.

157 Ibid.

operational fire department (professional or volunteer), available pressurized water supply (fire hydrants), and a fire protection bureau.[158] When fire departments receive a low score, it can affect the insurance rating of local government, municipalities, and individual property owner's insurance premiums.[159] It is crucial to achieve the best rating to ensure safety and reliability for the public while keeping insurance costs to a minimum.[160] Fire department staffing and capabilities correlate directly with a good ISO rating. It indicates that the infrastructure and fire department can mitigate emergencies in the areas they protect.

C. COMMON ISSUES OFTEN GO UNNOTICED

The focus of this research is crowd movement at outside events and their safety. The following section describes issues that may not be considered during planning or assessing the capabilities of a fire department. Each is important in its ability to decrease or increase the stability management at an outside event. Developing proper management at the scene of an event can bring order and decrease the time to mitigate any emergencies that may arise.

1. Self-Dispatching Creates Problems

Self-dispatch (self-deployment) is a term used by emergency departments indicating that an engine, truck, or medic company has taken it upon itself to deploy to an emergency without being summoned by a dispatcher.[161] Emergencies at crowded venues can attract self-dispatching from fire companies that are not part of the assigned equipment. It is human nature want to help during an emergency, more so when one is trained to assist injured people. However, self-dispatching often leads to chaos at the emergency scene.[162] Fire companies who deploy themselves are not part of the planned dispatch and therefore

[158] Ibid.

[159] Alan Wileman, "ISO Ratings Have Drastic Effect on Insurance Premiums," *Sierra Star*," April 15, 2015, http://www.sierrastar.com/news/article87806582.html.

[160] Ibid.

[161] Luiz Hargreaves, "Self-Dispatching in Emergencies and Disasters," Experts, accessed July 24, 2017, http://www.experts.com/Articles/Self-dispatching-Emergencies-Disasters-By-Dr-Luiz-Hargreaves.

[162] Ibid.

are unknown to command as they arrive on the scene. Upon arrival, these new personnel must be plugged into the system and given direction in a situation that may have already been set up and organized. Command is responsible for communicating a plan to arriving fire and EMS companies.[163] Emergency responders who self-deploy may become part of the emergency and hinder designated operations because dispatch did not account for them.

2. Mutual Aid Distributes Resources for the State and Nation

Fire departments enter into agreements with local, state, and federal agencies to assist during emergencies requiring additional personnel and equipment for short periods. Their use may be for any type of emergency including wildfires, floods, earthquakes, hurricanes, or manmade disasters, whether accidental or intentional.[164] There is not enough money in every department to supply equipment and personnel for every disaster that may arise. As a result, mutual aid agreements have evolved between departments to provide a means for requesting and lending assistance when one department does not have the full resources to mitigate an emergency. However, provisions in the agreements do not mandate that departments respond when called. Mutual aid is a tool to obtain help when available equipment is ready to react and routinely crosses jurisdictional boundaries. When fire department resources are depleted and unable to fulfill their agreement, the requesting department goes to the next available department on the master mutual aid list, which is maintained by state and federal agencies.

An important aspect of a mutual aid agreement is cost recovery for fire departments. Although the agreements are for short periods, multiple intrastate or federal requests for help can be made annually in California, for example, incurring a significant cost to responding agencies. Fire department's demand for reimbursement from the state or federal governments to repair fire apparatus and pay for labor can cause a burden on fire agencies. The losses a department experiences could lead to dropping out of a mutual aid program and decrease the statewide available pool of fire apparatus and crews. To prevent this

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163 Ibid.

164 "Mutual Aid Agreements and Assistance Agreements," Federal Emergency Management Agency [FEMA], accessed July 30, 2017, https://emilms.fema.gov/IS703A/RES0102130text.htm.

problem from arising, in 2004, FEMA developed Recovery Policy No. 9523.6 to ensure recovery of costs incurred during mutual aid deployments.[165] Cost recovery is a common area of concern for departments due to limited budgets and the time it takes to receive reimbursement from government agencies. Lessening the burden of labor and maintenance increases the possibility of executing mutual aid agreements.

3. Automatic Aid Helps Locally

Automatic aid is like mutual aid; however, it is used for a local response from neighboring departments.[166] For example, Sacramento Metro Fire, Folsom Fire, Sacramento City Fire, and Cosumnes Fire in California all have common jurisdictional boundaries and are partnered together by an automatic aid agreement. When emergency calls deplete available personnel and equipment, Sacramento Regional Fire Dispatch sends equipment from a neighboring department to the call. Depending on the type of emergency, units may respond from one, two, or all four agencies to mitigate the incident. When departments form an agreement, they need to consider the type of equipment and capability each respective department owns. Responding agencies must share the same capabilities as their neighboring agencies to ensure the same care. An essential aspect of the agreement is the rating from the ISO. One might question why ISO determines the acceptance of an agreement. As previously stated, ISO rates departments and their capabilities.[167] Consequently, companies having similar staffing, equipment, and capability are contracted for services between departments.

4. Volunteers Provide Valuable Service

Volunteers work tirelessly to provide a significant and valuable service to the members of their community. During extended emergencies, they assemble at the scene and work alongside emergency responders to help families restore their lives. Organized

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165 Daniel Craig, *Memo on 9523.6 Mutual Aid Policy* (Washington, DC: Federal Emergency Management Agency, 2005), https://www.fema.gov/9500-series-policy-publications/memo-95236-mutual-aid-policy.

166 “Mutual Aid Agreements and Assistance Agreements,” FEMA.

167 “Fire Suppression Rating Schedule,” ISO Mitigation.

charities may manage the services provided like the Red Cross, the Salvation Army, or other nonprofit organizations. In addition, there are groups of volunteers that have been trained by individual fire departments and law enforcement to respond not only to emergencies but to planned events as well.

The Community Emergency Response Team (CERT) members volunteer their services in cities and towns for extended periods, providing their services to support fire departments and help people. This organization got its start in Los Angeles in 1985.[168] By 1987, the Whittier Narrows earthquake provided to be a proving ground for the newly developed CERT members in the Disaster Preparedness Division of the Los Angeles County Fire Department.[169] By 1993, FEMA recognized the important role CERT held in emergencies, so the agency helped with training for individuals who wanted to become members.[170] As the program developed, the responsibility of CERT members morphed from disaster preparedness to medical operations, search, rescue, disaster psychology, organization, safety watch, and assistance at large venues.[171] Like firefighters, CERT members are called on for many tasks. They are professional and attend regular training and classes to maintain their certifications. Furthermore, their service is recognized as part of the incident command system and shares the same importance as other divisions.

D. INCIDENT COMMAND SYSTEM IMPORTANCE

Planning, organization, and strategy are critical factors that are part of the foundation of command. They are combined to direct task oriented tactics to mitigate an emergency. As the forward progression of the incident subsides, recovery starts. It is all made possible by use of the command system.

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[168] "About Community Emergency Response Team," Federal Emergency Management Agency, accessed July 30, 2017, https://www.fema.gov/about-community-emergency-response-team.

[169] Ibid.

[170] Ibid.

[171] Ibid.

1. Unified Command

Problems associated with one of the most devastating and expensive fires in California's history prompted U.S. Congress to authorize the formation of a system that would allow mutual operation between agencies.[172] It was called the unified command and was part of the newly developed Incident Command System (ICS) developed from 1970 California wildfires. More than 750 fires ignited that year during September and burned through October 4, 1970 in California. In just 13 days, 16 people were killed, 700 homes were destroyed, and 500,000 acres burned.[173] The responsibility of the unified command is to bring multijurisdictional agencies together and to prevent overlapping and redundant efforts for organization and management at an incident.[174] The position differs from a single incident commander, who is the sole authority at an incident that developed strategies and management. Unified commands share authority among several commanders from different agencies. They work together to produce the same structured information as a single incident commander.[175] The shared authority of supervisors at the unified command acts as one team and is able work much more efficiently as a result.

ICS was continually improved by the original authors: the California Office of Emergency Services, U.S. Forestry, California Forestry, and the Los Angeles, Ventura, and Santa Barbara County Fire Departments. The departments banded together to form an organization known as Firefighting Resources of California Organized for Potential Emergencies, agreeing to use standard system of organization and terminology.[176] ICS later became part of the National Incident Management System and became required

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172 Federal Emergency Management Agency [FEMA], *NIMS and the Incident Command System* (Washington, DC: Federal Emergency Management Agency, 2004), https://www.fema.gov/txt/nims/nims_ics_position_paper.txt, 1.

173 Thomas Henkey, *Urban Emergency Management: Planning and Response for the 21st Century* (Oxford: Butterworth-Heinemann, 2017), 87.

174 FEMA, *NIMS and the Incident Command System*, 3.

175 Ibid.

176 Ibid., 1.

training for all safety employees.[177] One of its components, the incident action plan (IAP), became one of the most used portions of ICS to distribute command and control.

2. Incident Action Plan

The IAP was developed as part of ICS to delineate the roles of individuals involved at an event or incident.[178] The IAP also includes all personnel, equipment, weather, maps of the operational area, operational periods, emergency medical information, and any other related information. Additionally, the IAP provides vital information to the members in the command structure: safety, liaison, public information officer, operations, planning, logistics, and finance are command positions to assist the operational objectives.[179] More importantly, the IAP provides the strategy and incident objectives at the scene as constructed by command. Consequently, the document must be meticulously updated at specified operational times, most often 12 or 24-hour periods. The periods allow changes in operations or development of the event or incident.[180] Additionally, the IAP can develop into the small city of individuals and equipment to support and maintain the needs of the firefighters working on the fire line. It may be constructed of only a few pages or more than a hundred. As an event or incident becomes more dynamic, so does the need for a changing plan.

E. CONCLUSION

Chapter III has explored many variables that may at first seem unrelated to crowd dynamics at outside events. However, it provides information to facilitate an understanding of some of the considerations for determining fire department capability, which affect fire department response. It is important to provide the services at an outdoor event to maintain the safety of the people. The information here further facilitates an understanding of how fire departments can develop partnerships with other agencies as a force multiplier when

177 Ibid.

178 Ibid., 4.

179 Ibid.

180 Ibid.

an agency requires additional help. Lastly, this chapter includes discussion on the importance of organization and management as well as how using several officials acting as one decreases workload and increases efficiency at an incident or event. The next chapter, Chapter IV, includes case studies that provide data that may reveal commonalities at outside venues to further understand crowd movement during an emergency.

IV. CASE STUDIES: A BETTER UNDERSTANDING OF CROWD MOVEMENT AND SAFETY

The following case studies provide information describing events and crowds that have experienced an incident at the venue they are attending. This chapter also discusses the planning and direction of public agencies responsible for the safety of attendees at large events. This research included data collection and analysis to determine root and contributing causes for each event.

A. CAUSAL FACTORS: FINDING THE PROBLEM

Causal factor determination for an incident asks the questions to answer who, what, when, and why. Problems arising from a given incident may be caused by any number of reasons, including human error, policy problems, or mechanical failure. This chapter uses portions of the Department of Energy's *Root Cause Analysis Guide* to determine causal factors for the case studies. The assessment includes four parts. The first step is to establish the background and identify the problem with concurrent data collection.[181] The second step is to establish data on crowd structure.[182] The third step is to use the data to establish the significance of the problem and identify conditions, actions, and possible causes.[183] The fourth and final step is to establish the root cause(s) for each incident. This research uses root cause analysis to determine if the given event could have been prevented by corrective action prior to the event.[184] These four parts provide a comprehensive look to determine a root cause associated with each case study.[185] It is also important to be objective when gathering data and to avoid making assumptions. The evidence should control and direct the investigation to produce the most probable explanation.[186]

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[181] U.S. Department of Energy, *Root Cause Analysis Guidance*, 1.

[182] Ibid.

[183] Ibid.

[184] Ibid.

[185] Naomi Brimmer, "Root Cause Analysis Template," State of Indiana, accessed June 14, 2017, https://www.in.gov/fssa/files/008_Root_Cause_Template__BQIS_11215.pdf.

[186] U.S. Department of Energy, *Root Cause Analysis Guidance*, 3.

B. ROOT CAUSE: PREVENTING RECURRENCE

This thesis uses root cause analysis to investigate and analyze circumstances relating to incidents at large, crowded events. There may be many contributing causes that may emerge after an incident. However, it is important to determine the root cause at an incident so as to prevent the problem from happening again at another event. The root cause at one event may also affect other events differently causing entirely new problems. The process for determining a root cause is through a process similar to risk assessment. The goal of root cause is to interpret and reveal the specific cause of the incident by providing an impartial investigation.[187]

C. CASE STUDIES OF CROWD ASSESSMENT AND SAFETY

The case studies in this chapter are from incidents at outside public venues. The researcher chose the events for three reasons. First, they all have significant incidents that test the ability of emergency services to mitigate the problem. Second, specific information is available on each event can be found in published government reports and analysis. Finally, the events are related to crowd movement in an emergency. Each study begins with a description of the venue, crowd location, seating (if available), and egress. The research includes three variables: crowd structure, causal factors, and root cause. The thesis examines and describes crowd structure. The researcher determined causal factors for each incident from source information. Finally, this thesis lists the causal factors of the case study events and presents the root cause if known. The case studies, arranged chronologically, are as follows: 1989 Hillsborough soccer match, 2011 Reno Air Race, the 2013 Boston Marathon, and the 2014 Travis AFB Air Show.

1. Hillsborough Soccer Match Tragedy

Soccer fans entered Hillsborough Stadium in Sheffield, England on April 15, 1989, with anticipation of watching a match between Liverpool and Nottingham Forest.[188] They

[187] Ibid.

[188] Hillsborough Independent Panel, *Hillsborough: The Report of the Hillsborough Independent Panel* (London: The Stationary Office, 2012), http://hillsborough.independent.gov.uk/repository/report/HIP_report.pdf.

were unaware of several discussions addressing the safety of the outdoor stadium by the fire department, the police, and the owners of the stadium.[189] Prior to the event, the South Yorkshire Fire Commission (SYFC) provided a complete safety inspection to discover safety problems at the stadium.[190] The stadium had a history of inadequate safety features that were life safety concerns and had not yet been resolved properly. The owners had been unable to obtain a safety certificate after multiple renovations to enlarge entry turnstiles and a tunnel. The tunnel led to areas designated as "pens," areas to hold patrons.[191] The pens and their gates had also been renovated and were located at the end of the entrance tunnel. Unfortunately, the renovated turnstiles, gates, and the tunnel were significantly smaller than the recommended size, which impeded safe exiting.[192]

As people began moving through the turnstiles the day of the match, the crowded created a bottleneck and forward progress slowed. As the 3:00 p.m. game time drew near, police requested holding the start of the game until fans could get inside the stadium. Meanwhile, several police officers complained about the problems from the building density of the crowd outside the stadium. A police superintendent ordered an officer to open a larger gate to allow patrons to enter the stadium; this created a rush of incoming fans.[193] The resulting crowd crush injured hundreds and killed 96 men, women, and children (see Figures 5 and 6).[194] Injury and deaths were created by the sudden rush of people moving through the side gate. Commonly called crowd crush, the tremendous weight and force of the crowd threw people to the ground and against fences, preventing them from breathing.[195] The coroner's reports indicated traumatic asphyxia, a sudden

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[189] Ibid., 7.

[190] Committee of Inquiry into Crowd Safety and Control at Sports Grounds [Committee of Inquiry], *Committee of Inquiry into Crowd Safety and Control at Sports Grounds: Final Report* (London: Home Office, 1986), http://bradfordcityfire.co.uk/wp-content/uploads/2013/02/popplewell-final-report-1986.pdf, 21.

[191] Hillsborough Independent Panel, *Hillsborough*, 7.

[192] Ibid.

[193] Patrick Sawer, "What Happened at Hillsborough in 1989?," *The Telegraph*, April 15, 1989, http://www.telegraph.co.uk/news/0/happened-hillsborough-1989/.

[194] Hillsborough Independent Panel, *Hillsborough*.

[195] Still, "Crowd Dynamics: Thesis," 10.

inability to breathe, as the cause of death for fans.[196] A two-minute YouTube video animation produced by Reuters depicts realistic movement of the crowd surging in to see the start of the match and also shows the relative numbers of people.[197] Although an inquiry started in 1989, a trial indicting police officers did not conclude until 2012. People complained that the police were in charge of the public safety, and actions by the police resulted in death and injury. Police officers were later charged with the deaths and injury of fans at the Hillsborough match, while the fire service, EMS, and the stadium owners were not included in the indictment.[198] Supervising police officer David Duckenfield, Sir Norman Bettison, and four additional police officers were charged with the responsibility of the incident that took place.[199]

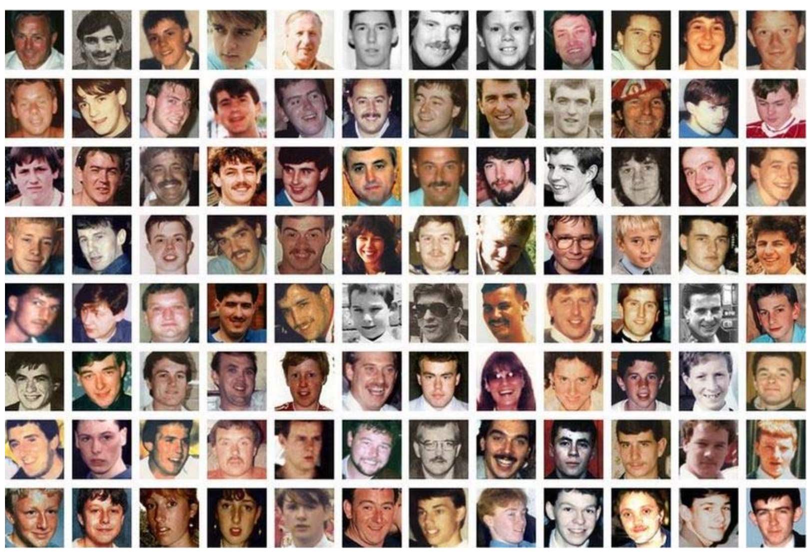

Figure 5. Picture of 96 Persons Who Perished at Hillsborough Stadium 1989[200]

[196] Ibid.

[197] News Direct, "Hillsborough Tragedy: A Reconstruction," YouTube, October 15, 2012, https://youtu.be/mCFuQLUD-LQ.

[198] "How the Hillsborough Disaster Happened," *BBC News*, April 15, 1989, http://news.bbc.co.uk/2/hi/uk/7992845.stm.

[199] Sawer, "What Happened at Hillsborough."

[200] Source: Simon Rice, "Hillsborough Anniversary: 96 Reasons to Pay Tribute," April 15, 2015, *Independent*, http://www.independent.co.uk/sport/football/news-and-comment/hillsborough-anniversary-96-reasons-to-pay-tribute-10177399.html.

Figure 6. Picture of People Killed by Asphyxia and Pens Where They Died[201]

a. Crowd Structure

Men, women, and children were all hurrying along the streets of Sheffield to arrive at the Hillsborough soccer match on time. Many of the fans arrived from other cities via mass transit. Because of their various modes and origins of travel, not everyone arrived on time for the game at the Hillsborough stadium on Leppings Lane.[202] The narrow street acted like a funnel moving the crowd closer to the entry turnstiles. The crowd of fans was so dense that traffic on the street was unable to move.[203] When they were finally able to reach the stadium, fans found the crowd had become denser and was not moving due to the relatively few number of turnstiles available through which to enter the stadium. People began complaining and becoming "unruly, nasty, and violent," as stated by police officers.[204] Police officers on foot and horseback were unable to manage the crowd and ultimately became part of the initial crowd crush that started outside the turnstiles.[205]

201 Source: Nico Hines, "U.K. Court Blames Police, Not Soccer Fans, for Hillsborough Disaster, April 26, 2016, *The Daily Beast*, http://www.thedailybeast.com/uk-court-blames-police-not-soccer-fans-for-hillsborough-disaster. Rice, "Hillsborough Anniversary.

202 Hillsborough Independent Panel, *Hillsborough*, 37.

203 Horror Stories, "Hillsborough Stadium Disaster," YouTube," June 7, 2017, https://www.youtube.com/watch?v=8AWGVYpAaQc&t=1s.

204 Hillsborough Independent Panel, *Hillsborough*, 37.

205 Ibid.

b. Causal Factors

Several problems at the Hillsborough Stadium contributed to the severity of incident. Although many of the fans were already in place at the stadium, many more were attempting to get in when the crush occurred. As the time for the match to start drew nearer, people become anxious.[206] Police realized that the number of turnstiles could not accommodate the number of fans.[207] Ticketless fans also arrived at the stadium and became part of the crowd, adding to the increasing crowd density and slow progression into the stadium.[208] As one of the officers outside the gate, Officer Roger Marshall requested help via radio and asked permission to open the side gates because people were getting crushed at the turnstiles. His colleagues in an observation booth recognized the increasing density of the crowd; however, Commander Roger Greenwood, operating inside the gates, had no knowledge of what was happening or about to happen.[209] Thinking it would release the tension on the inadequate turnstiles, newly promoted Chief Superintendent David Duckenfield gave the order to open the side gate and allow people in.[210] When the crush began, people were thrown against wire fences and to the ground unable to move.[211] Demands by the police to stop the match as injuries were happening initially went unheeded by match officials.[212]

The injuries occurred in the pens constructed in 1981 by owners of the stadium. These pens were designed to prevent previous problems with fans who were unruly at matches.[213] The pens were also designed to prevent patrons from getting onto the playing field, which was a constant problem at games, and fighting with fans from the opposing teams. The pens proved to be a significant part of the problem since people were pushed

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[206] Ibid.

[207] Ibid., 9.

[208] Committee of Inquiry, *Committee of Inquiry*, 5.

[209] Hillsborough Independent Panel, *Hillsborough*, 8.

[210] Sawer, “What Happened at Hillsborough?”

[211] Horror Stories, “Hillsborough Stadium Disaster.”

[212] Sawer, “What Happened at Hillsborough?”

[213] Hillsborough Independent Panel, *Hillsborough*, 6.

into them by the crowd's rush.[214] The walkway leading to the pen openings was at a steep angle, which increased the speed of traffic into the pens.[215] Investigators cited the width of the gate doors as part of the reason for the crowd crush; they were not wide enough to allow proper entry or exit.[216] The capacity of each of the five pens was 1,600 people; however, there were an estimated 2,200 people in each of two center pens at the time of the crush.[217] The final Hillsborough report stated police officers kept pen exit gates closed and locked. Having the gates locked posed an exit hazard that the fire department had not addressed in its planning.[218] However, lack of police gate monitoring proved to be a key component of the problems with the pens.[219]

When the injuries started, police called for ambulances to assist the injured. Unfortunately, the dense crowd prevented medics from arriving in a timely manner. As the ambulance crews tried to drive their vehicles near the pen areas, fans and police officers attempted to help move the critically injured and perform cardiopulmonary resuscitation. The medics on the ambulances were also overwhelmed and unable to establish treatment and triage areas to manage patients and their transport to hospital.[220] The ambulance services did not alert local hospitals about the multicasualty incident, which meant that hospitals did not prepare in time for the number of people arriving.[221] As a result, the number of patients arriving quickly overwhelmed the hospital's emergency room capability.[222]

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[214] Ibid., 8.

[215] Ibid., 73.

[216] Hillsborough Independent Panel, *Hillsborough*, 73.

[217] "How the Hillsborough Disaster Happened," *BBC News*.

[218] Hillsborough Independent Panel, *Hillsborough*.

[219] Health and Safety Executive, "Managing Crowds Safely: A Guide for Organisers at Events and Venues—HSG154," 1996, http://www.hse.gov.uk/pubns/books/hsg154.htm.

[220] Hillsborough Independent Panel, *Hillsborough*, 13.

[221] Ibid., 138.

[222] Ibid., 13.

SYFC had relatively little involvement at the scene but were instrumental in preliminary planning and reporting of issues of concern with the safety of the stadium.[223] SYFC became understandably concerned for the safety and welfare of fans due to the radical changes installed by the owners of the stadium three years prior, preventing the free flow of pedestrian traffic.[224] SYFC also stressed the need for the owners to provide a valid safety inspection and certificate before allowing the use of stadiums; however, police did not think it was necessary.[225] Additionally, SYFC understood and agreed with police that fans were causing many of the problems associated with challenging police authoity at matches.[226] However, they asserted, the safety and security of the fans was a greater concern that needed to be addressed by the police.[227] Still, neither the fire department nor the police developed a plan for large crowds attending an event at the stadium.[228]

SYFC and the stadium owners used a publication called the *Guide to Safety at Sports Grounds* (Green Guide) to calculate tolerances with crowd numbers.[229] The Green Guide is an internationally accepted and consulted guide for all aspects of safety at sports venues, including safe exiting.[230] SYFC informed the owners and police of the failure to comply with the guide, yet the owners made no changes for safety.[231] Information in the guide also indicated the areas in question for crowd density should be evacuated in eight minutes or less should there be an emergency. The calculation determined by SYFC indicated that exiting would take more than 11 minutes to evacuate each area.[232] The owners of the stadium also made many safety calculations that fell short of the required

[223] Ibid., 7.

[224] "How the Hillsborough Disaster Happened," *BBC News*.

[225] Hillsborough Independent Panel, *Hillsborough*," 29.

[226] Committee of Inquiry, *Committee of Inquiry*, 6.

[227] Ibid.

[228] Hillsborough Independent Panel, *Hillsborough*.

[229] Department for Culture, Media and Sport, *Guide to Safety at Sports Grounds*, 5th ed. (London: Department for Culture, Media and Sport, 2008), http://www.safetyatsportsgrounds.org.uk/sites/default/files/publications/green-guide.pdf.

[230] Ibid.

[231] Hillsborough Independent Panel, *Hillsborough*, 85.

[232] Ibid., 67.

minimums as reported by SYFC, but neither police nor EMS overseeing safety security and management did anything about the problems.[233] SYFC reported its calculations for safe exiting prior to the match, indicating passages and the areas around the pens and in the tunnels leading to the pens were too narrow and crowd density too large.[234]

c. Root Cause

Lord Justice Taylor chaired the independent panel that examined the incident at Hillsborough. The final report of the panel indicated that the responsibility for the Hillsborough incident fell on stadium owners, police, EMS, and fire services.[235] His statement directly contradicted 1989 comments by the police, who blamed the fans for the crowd crush.[236] Additionally, Taylor reported three reasons for the Hillsborough tragedy: layout of the grounds, the opening of the gate near the turnstiles, and the build-up of the crowd. He stated that the grounds were the responsibility of police and fire; however, they were not able to control crowd movement and instill safety.[237] Although unchallenged in their remarks, Taylor and the Hillsborough Independent Panel concluded that there are relatively few times when one single cause can be attributed to an incident.[238] Although the panel reported that the responsibility belonged to the owners and all of emergency services, in 2012, British court claimed the police were at fault for the incident at Hillsborough in 1989.[239] There were many contributing factors that caused the incident at Hillsborough. It is important to note the list of problems that contributed to the tragedy:

- Large crowd was unable to move through the available turnstiles.
- Ticketless fans were part of the crowd and contributing to the crowd density and inability to move smoothly through the few turnstiles available.
- Police were becoming part of the crowd and its inability to move.

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[233] Ibid., 68.

[234] Ibid., 85.

[235] Ibid., 210.

[236] Sawer, “What Happened at Hillsborough?”

[237] Hillsborough Independent Panel, *Hillsborough*, 210.

[238] Ibid., 61.

[239] Nico Hines, “U.K. Court Blames Police.”

- Police were overwhelmed by the crowd numbers.
- Inadequate leadership by the newly appointed police supervisor prevented proper. command.
- Side gate was opened to relieve crowd pressure on the turnstiles.
- Crowd crush
- Pens were the location for the crowd crush.
- Victims were pushed to the ground and against fences and unable to breathe.
- Inadequate and flawed design of the fences, tunnel, and walkway.
- Ambulances were not staged at the event, consequently slowing their response.
- EMS personnel could not drive near the pens where the incident occurred due the crowd density
- Ambulance supervisors did not alert the hospitals of the multicasualty incident.
- Hospital emergency rooms were overwhelmed.
- SYFC reported the stadium did not comply with fire and exiting standards prior to the incident.
- There were more fans than there was available space, as confirmed by the Green Guide.

2. Reno Air Race

Beginning in 1964, the annual Reno Air Race has been staged annually for more than 50 years.[240] It has grown from a dirt runway with a few spectators to more than 150,000 fans over a four-day weekend.[241] On September 16, 2011 almost 30,000 fans arrived in one day at the Reno-Stead Airport parking lot, making their way to the bleachers and boxed seating areas.[242] During one of the races, all the aircraft turned the corner at

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[240] "Celebrating 50 years of the Reno Air Races," *Reno Gazette-Journal*, September 16, 2013, https://www.usatoday.com/story/travel/flights/2013/09/16/reno-air-races-fiftieth-anniversary/2820923/.

[241] Associated Press, "Reno Air Races Sees First Profit Since 2011 Crash," *KOLO 8 News Now*, November 12, 2015, http://www.kolotv.com/home/headlines/Reno-Air-Races-Sees-First-Profit-Since-2011-Crash-347069272.html.

[242] Lucas Wimmer, "Webinar Reviews EMS Response to 2011 Reno Air Race Crash," EMSWorld, November 13, 2015, http://www.emsworld.com/article/12138459/webinar-reviews-ems-response-to-2011-reno-air-race-crash.

pylon eight, flying the designated course directly at the seated crowd, indicated by Figures 7 and 8. At one point, a single aircraft lost control and crashed into the crowd.[243] It struck the boxed area where there were comparatively fewer spectators than those seated in the grandstands. However, the impact was devastating (see Figures 7–10).[244] Spectators witnessed the incident, which killed 11 people and injured more than 60.[245] Crashes are not uncommon at the race; however, precautions have been taken to prevent problems.

Figure 7. Satellite Photo with Course Overlay[246]

[243] "Death Toll Rises in Reno Air Show Crash," *NBC News*, September 18, 2011, http://www.nbcnews.com/id/44556695/ns/us_news-life/t/death-toll-rises-reno-air-show-crash/.

[244] Ken Ritter and Scott Sonner, "NTSB: Trim Tab Failure Caused 2011 Reno Race Crash," *The San Diego Union-Tribune*, August 27, 2012, http://www.sandiegouniontribune.com/sdut-ntsb-trim-tab-failure-caused-2011-reno-race-crash-2012aug27-story.html.

[245] National Transportation Safety Board [NTSB], *Pilot/Race 177, The Galloping Ghost, North American P-51, N79111* (NTSB/AAB-12/01 PB2012-102899) (Washington, DC: National Transportation Safety Board 2012), https://www.ntsb.gov/investigations/AccidentReports/Reports/AAB1201.pdf.

[246] Source: "National Championship Air Races, Unlimited Couse, Reno, Nevada [image]," National Transportation Safety Board, accessed October 15, 2016, https://www.ntsb.gov/news/events/PublishingImages/Poster_1.png.

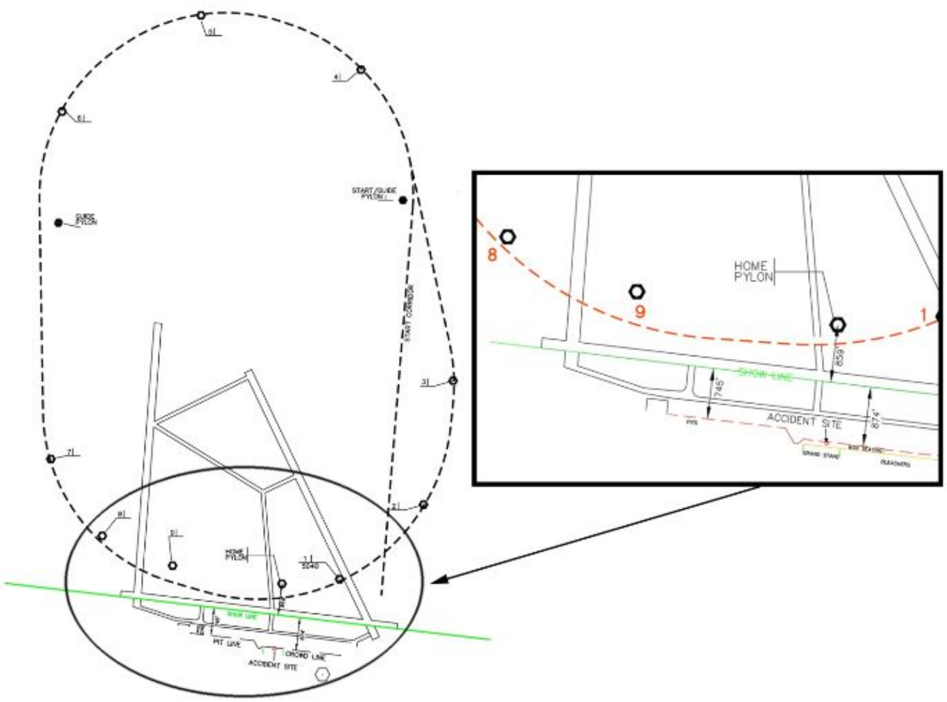

Figure 8. Race Course Schematic: Note Accident Site in Box near Pylon 8[247]

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[247] Source: Deborah A. P. Hersman, *Safety Recommendation* (A-12-13 through -17) memo to Michael Houghton, Reno Air Racing Association (Washington, DC: National Transportation Safety Board, 2012), https://www.ntsb.gov/safety/safety-recs/recletters/A-12-013-017.pdf.

Figure 9. Trim Tab Missing on Aircraft[248]

Figure 10. Impact of Aircraft[249]

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[248] Source: Mike Danko, "NTSB Cites Flutter as Cause of Reno Air Race Crash," *Aviation Law Monitor* [blog], August 29, 2012, http://www.aviationlawmonitor.com/tags/p51-crash-at-reno/.

[249] Source: Jesse McKinley, "Spectators' Deaths Highlight Risk of Popular Aerial Racing," *New York Times*, September 17, 2011, http://www.nytimes.com/2011/09/18/us/reno-air-show-crash.html.

At an air race such as the one in Reno, crowd protection is paramount, and this prompts annual inspections and planning. The Reno Fire Department trained in scenarios to ensure proper response by its assets and emergency medical services.[250] Training included both tabletop and live scenarios to replicate possible incidents.[251] For example, representatives from the local emergency services, emergency management, county medical examiner, Air and Army National Guard, county hospitals, coroner's office, and law enforcement participated in an exercise with four scenarios with live actors on May 25, 2011.[252] , Also prior to the race, on June 2, 2011, representatives from the same agencies participated in a table top exercise that simulated 23 fatalities and 46 injured individuals.[253] Having received specific instructions for their mock injuries, volunteer actors wore makeup to provide a realistic scene for the exercise. These exercises provided real-world training to mimic actual situations with time monitoring to determine response, treatment and transport of patients, and scene mitigation.

a. Crowd Structure

On September 17, 2011, people of all demographics quickly filled the aluminum bleachers and preferred box seating area. The third day of air races was as successful as the prior two days, generating significant crowd numbers.[254] The majority of the crowd was seated on elevated bleachers and packed tightly to fill the available space, while more than 1,000 were at ground level in a preferred area located in front of the bleachers.

b. Causal Factors

The weather posed no significant issues during this incident as per National Transportation Safety Board (NTSB). The temperature was 82 degrees with winds from the southwest at 15 mph. According to a 2011 NTSB report, there were also expected 21

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[250] Paul Nelson, "Hundreds Team Up for Reno-Tahoe Int'l Airport Disaster Drill," *CBS 2 News KTVN*, last updated May 3, 2017, http://www.ktvn.com/story/35269150/hundreds-team-up-for-reno-tahoe-intl-airport-disaster-drill.

[251] NTSB, *Pilot/Race 177, The Galloping Ghost*.

[252] Ibid.

[253] Ibid.

[254] Wimmer, "Webinar Reviews EMS Response."

mph gusts with visibility of 10 miles. The information is a standard weather briefing given before flight by the National Weather Service and is essential for safe flying.[255]

The portion of the crowd sitting on the bleachers had less individual seating space per person than the fans in the preferred area, decreasing the ability of the fans in the bleachers to exit swiftly in an emergency (see Figure 11). Preferred seating had sectioned areas with tables, chairs, and umbrellas, and the space could not accommodate the same density of patrons as people seated on the bleachers (see yellow highlighted area in Figure 12). As shown in Figure 11, the positions of the seating were built for spectators to obtain the best view of the air races.

Figure 11. Elevated Grandstands[256]

[255] NTSB, *Pilot/Race 177, The Galloping Ghost*.

[256] Source: Shawna Malvini Redden, "Mourning the 2011 Reno Air Races," *The Bluest Muse* [blog], September 18, 2011, http://www.bluestmuse.com/2011/09/mourning-2011-reno-air-races/.

Figure 12. Reno Air Race with Boxed Seating in Yellow with Elevated Grandstands[257]

During the third race, the pilot flying the *Galloping Ghost* (P-51D) began to experience fluttering in the fuselage of the aircraft as he flew at almost 500 mph.[258] High-speed photography captured evidence that would later reveal several faulty items were critical to the plane's structural stability. The NTSB determined that there were several critical factors on the aircraft indicating reasons for structural failure, among them were:

- Windscreen and canopy ajar, and are normally closed in flight.[259]
- Wrinkles in the skin aft of the wings were found on both sides, indicating structural failure.[260]

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[257] Source: "National Championship Air Races Ramp Area [image]," National Transportation Safety Board, accessed April 29, 2017, https://www.ntsb.gov/news/events/PublishingImages/Poster_2.png.

[258] NTSB, *Pilot/Race 177, The Galloping Ghost*, 30.

[259] Ibid., 34.

[260] Ibid., 23.

- The tail wheel was in the down position, which is normally up while flying.[261]
- The pilot was not visible in the cockpit, indicating that he was not in control of the aircraft and very possibly unconscious due to gravitational forces.[262]
- The trim tab broke off the aircraft's left horizontal elevator preventing normal flight. (as seen in Figure 7).[263]

History of the work done on the *Galloping Ghost* reveals several changes were made.[264] The owner of *Galloping Ghost* and his team continually modified the aircraft to achieve better results for racing.[265] The modifications made by the *Galloping Ghost* crew were undocumented and without drawings.[266] The problems multiplied since the owners of the aircraft did not complete an analysis on the modified structure to prove its airworthiness—a crucial factor, according to the NTSB.[267] Additionally, there was no inspection or authorization by the Federal Aviation Administration (FAA), which would have provided certification only if the craft proved safe and airworthy. The Reno Air Race Association (RARA) was responsible for authorizing aircraft to fly. The application submitted by the pilot declared that there were no modifications done on his plane, and the RARA accepted this.[268] Upon interviewing ground crew and other associates, the NTSB could not determine reasons for many of the modifications on the aircraft. Some of the changes caused opposite aerodynamic effects, which affected speed and stability.[269] Most important was the change to the control surfaces, a small horizontal wing (a called trim tab) at the rear of the aircraft located on the rear elevators (shown in Figure9). The tabs are small, movable surfaces that the pilot adjusts to relieve pressure on the control stick and decrease pilot effort during flight. Inexplicably, the trim tab on the right side of the aircraft

261 Ibid., 32.

262 Ibid., 19.

263 Ibid.

264 Ibid.

265 Ibid.

266 Ibid., v.

267 Ibid.

268 Ibid., 28.

269 Ibid.

in a fixed position while the trim tab on the left had been modified with larger bolts to hold it onto the aircraft and untested before the race.[270]

During the race, the aircraft began to flutter under the stress of the modifications, causing the nuts holding the modified trim tab to loosen.[271] The high stress on the parts caused them to fail, sending the aircraft spiraling up, until the leading edge of the wings stalled, rendering the pilot unconscious due to gravitational forces. The plane then quickly spiraled down into the boxed seating section where the impact took the lives of 11 people and injured many more.[272]

All fans were seated and in direct line of the failed aircraft. Additionally, the majority seated on bleachers, that were up to 30 rows high, slowing the crowd's ability to exit. Patrons located in the box seating area were surrounded by tables, chairs, and partitions, which made exiting slow and cumbersome as evidenced by a YouTube video of the scene of the crash.[273] The video also shows how quickly the incident happened. People were unable to react prior to the impact.[274] However, after the impact, they responded slowly and methodically, without panic.[275] The crowd response to the emergency remained uncoordinated but calm as spectators exited and attempted to help family and friends.[276] Firefighters and other emergency responders staged at scene began immediately treating trauma victims at the scene.

The plane crashed straight down into the ground, which meant that it did not slide a great distance, and this meant fewer injuries. However, the force of the impact was so great that parts of the aircraft flew off and traveled great distances, severing body parts and

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[270] Ibid.

[271] Ibid.

[272] Ibid.

[273] Kyle Wilson, "Dramatic New Video: Moment of Reno Plane Crash Caught on Camera," YouTube, September 22, 2011, https://www.youtube.com/watch?v=Thd7ZqjclZE.

[274] Ibid.

[275] Scott Sonner, and Ken Ritter, "Calm Chaos Followed Nevada Air Show Disaster," *Seattle Times Newspaper*, September 19, 2011, http://old.seattletimes.com/text/2016245385.html.

[276] Wilson, "Dramatic New Video."

creating massive head injuries.[277] The injuries were horrific and challenged the experience and knowledge of firefighters on scene, who have never dealt with this level of trauma.[278] However, the training just three months earlier helped firefighters bring order to the scene. Firefighters quickly set up treatment and triage and ordered additional ambulances.[279] Off-duty firefighters and civilians also came from the crowd to help take care of the injured,[280] They worked alongside firefighters, packaging patients, and attempting to stop their bleeding. Several witnesses noticed the calm way the fire department managed and mitigated the scene, transporting all critical patients in just over an hour.[281]

c. Root Cause

The root cause of the Reno Air Race incident was due to many mechanical errors and failures on the aircraft, according to the NTSB.[282] The data analyzed in this research also found that the pilot of the failed aircraft did not fill out paperwork properly. The RARA application submitted by the pilot declared that there were no modifications done to his aircraft in the previous two years. Additionally, the RARA failed to confirm the information that would have prevented the pilot and aircraft from flying in the race. Moreover, the pilot and his team elected to make modifications on the plane without testing or receiving proper approval, which ultimately cost people their lives.

The focus of this study is examination of crowd response in emergencies. However, it is necessary to include information about the aircraft incident to understand what happened and how the crowd was affected. Below is a list of contributing causes:

- Dense crowd was seated directly in the flight path of aircraft traveling at high speeds.

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[277] Sonner, and Ritter, "Calm Chaos Followed."

[278] Ibid.

[279] Wimmer, "Webinar Reviews EMS Response."

[280] Kathleen Merryman, "Tacoma Firefighters Describe Response to Reno Air Show Tragedy," *The News Tribune* [Tacoma], October 1, 2011, http://www.georgiaems.org/tacoma-firefighters-describe-response-to-reno-air-show-tragedy/.

[281] Wimmer, "Webinar Reviews EMS Response."

[282] NTSB, *Pilot/Race 177, the Galloping Ghost.*

- Additional exiting, which would have allowed people to leave the area faster, was not indicated or noted in the research.
- Preferred seating area was boxed in by fences and multiple tables, chairs, and umbrellas, which prevented swift exiting of people.
- Fences around preferred seating area were not solid and did not provide protection from flying debris.
- Incorrectly filled out RARA report by pilot and owner of *Galloping Ghost*.
- RARA did not verify information on the application submitted by the pilot.

Reasons for the successful responses by the fire department are as follows:

- Fire department and multiple agencies planned for a multicasualty incident prior to the race.
- Hospitals and the healther departments were involved with event planning.
- Fire department was staged on scene during the race.
- Ambulance companies were staged on scene at the race.
- Off-duty firefighters and civilians assisted with patient care.

3. Boston Marathon

In Boston, all emergency response agencies, trauma hospital officials, Office of Emergency Management officials and more than 40 other associated agencies involved with the 2013 marathon were part of planning.[283] The race had taken place the third Monday of every April since 1897.[284] The focus of this case study is not on the terrorist activity; rather, it is a study of the reaction from the public agencies, spectators, and runners during a disaster. The planner's strategy covered the beginning of the race 26.2 miles away and extended to the finish line in downtown Boston. Planning focused on the health and

[283] Massachusetts Governor's Office, *After Action Report for the Response to the 2013 Boston Marathon Bombings* (Boston: Massachusetts Governor's Office, 2014), http://www.mass.gov/eopss/docs/mema/after-action-report-for-the-response-to-the-2013-boston-marathon-bombings.pdf.

[284] Wayne Dion, "2013 Boston Marathon Photos," *Framington News*, April 15, 2013, http://www.framingham.com/news/2013/04/15/health-fitness/2013-boston-marathon-photos/.

safety of every citizen along the route, whether they were athletes or fans.[285] Cytel Corporation's James Baker, who assisted with planning for emergencies, said there were not many cities that planned for possible problems like Boston did.[286]

The race started on time and without incident, allowing almost all the runners to reach the finish line. At 2:59 p.m., with 5,000 athletes left to complete the race, an explosion rocked several buildings near the finish line.[287] When the explosion occurred, it created a wave of people attempting to flee the area. Then, approximately 15 seconds later, a second explosion erupted approximately 500 feet away from the first blast indicated by the pictograph (see Figure 13).[288] The second bomb confused people, and they changed direction in a fight to save their lives. The blasts killed three people, injured 264, and left 16 with traumatic amputations.[289] Much like the incident at the Reno air race, victims sustained horrific injuries, causing tremendous blood loss.

People ran to the injured and began helping with triage and making bandages to assist the injured in a heroic attempt to save lives. Many people attempted to stop victim's bleeding by applying tourniquets made from belts and shirts to stave off the shock and probable death.[290] Boston trauma surgeons later hailed the use of tourniquets as a probable lifesaver for many of the victims.[291] People helping patients continued to work with first responders, who arrived very quickly on the scene. Everyone continued to work together, moving the patients to the triage area. All critically ill patients were triaged and made ready

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[285] *Testimony before the House Committee on Homeland Security: The Boston Bombings: A First Look* (2013) (Kurt Schwartz, Undersecretary for Homeland Security and Homeland Security Advisor), http://docs.house.gov/meetings/HM/HM00/20130509/100785/HHRG-113-HM00-Wstate-SchwartzK-20130509.pdf, 6.

[286] Henry Grabar, "Boston Is One of the Best Prepared U.S. Cities to Handle a Crisis," CityLab, accessed October 15, 2016, http://www.theatlanticcities.com/neighborhoods/2013/04/boston-one-best-prepared-us-cities-handle-crisis/5308/.

[287] Massachusetts Governor's Office, *After Action Report*, 4.

[288] Ibid.

[289] *Testimony before the House Committee* (Schwartz), 4.

[290] Mike Strobe, "Once-Doubted Tourniquet Seen as Boston Lifesaver," *San Diego Union-Tribune*, April 17, 2013, http://www.sandiegouniontribune.com/sdut-once-doubted-tourniquet-seen-as-boston-lifesaver-2013apr17-story.html.

[291] Ibid.

for transport within 40 minutes.[292] Although some patients were transported by cars, 73 ambulances had been committed to the incident and delivered all viable patients to trauma centers.[293]

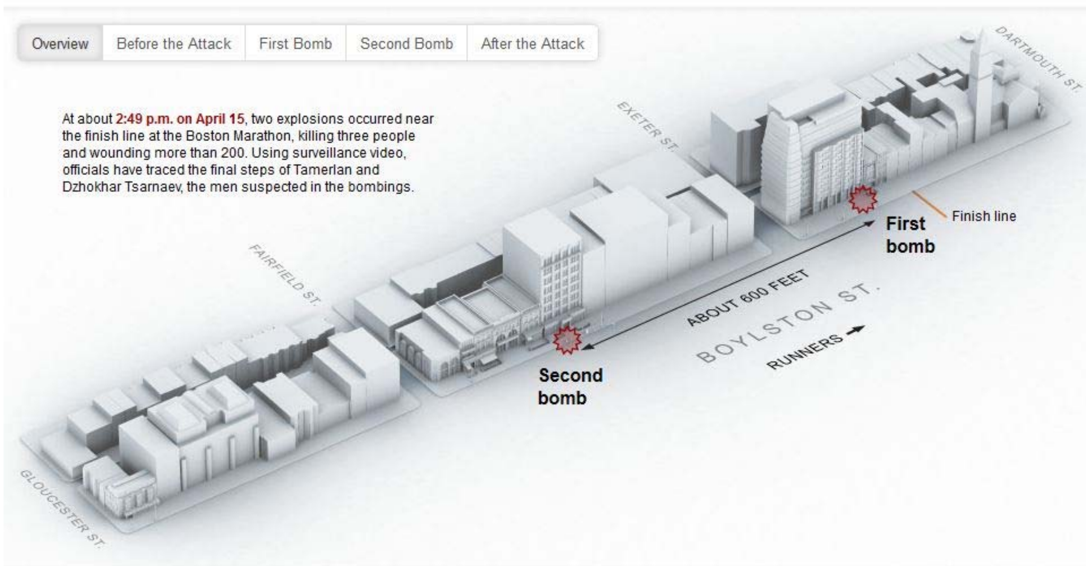

Figure 13. Boston Marathon Explosion Locations near Finish Line[294]

a. *Crowd Structure*

More than 27,000 people lined up at the starting line in Hopkinton, Massachusetts, on April 15, 2013 for the annual Boston Marathon.[295] The diverse crowd of athletes were from around the globe, bringing their trainers, family, and friends to help them along the course. They were cheered to the finish line by fans who lined the streets from every town along the way. The runners trekked through eight towns on their way to downtown Boston on Boylston Street to the finish line.[296]

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[292] Massachusetts Governor's Office, *After Action Report*.

[293] Ibid., 82.

[294] Source: "Reconstructing the Scene of the Boston Marathon Bombing," *New York Times*, last updated April 23, 2013, http://www.nytimes.com/interactive/2013/04/17/us/caught-in-the-blast-at-the-boston-marathon.html.

[295] Dion, "2013 Boston Marathon Photos."

[296] *Testimony before the House Committee* (Schwartz).

b. Causal Factors

Months in advance of the Boston Marathon, several agencies met to develop a mock training exercise in preparation for emergencies.[297] The Massachusetts Emergency Management Agency put together a team that included all emergency responders, Emergency Operations Center, Office of Emergency Services, National Guard, Boston Athletic Association, Department of Health, FAA, and many other agencies to form a cohesive training group.[298] The group also included officials from all emergency responder agencies in the three counties that would be affected along the 26.2-mile route for the race. Their directive from the state of Massachusetts was to train for almost any conceivable catastrophe and how it could be mitigated. Another goal was for stakeholders to network before the event rather than exchange business cards at the scene.[299] The group learned very early the way to get work done quickly and efficiently was to know the people involved.[300] Additionally, the group was dedicated to training and preparation from the beginning of the race in Hopkinton to the end in Boston.[301]

Assistance from the Department of Homeland Security played a major role by issuing a grant for homeland security. Boston was designated as a tier 1 U.S. city by the Department of Homeland Security, since it had a high likelihood of a terrorist event.[302] The Urban Area Security Initiative (UASI) allocated 500 billion dollars in fiscal 2012 to 31 different American cities for equipment and training; Boston's share was 11 million dollars.[303] The training exercise with all agencies that were part of safety planning in

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[297] Massachusetts Governor's Office, *After Action Report*, 2.

[298] *Testimony before the House Committee*, 3.

[299] Committee on Homeland Security and Governmental Affairs, *Lessons Learned from the Boston Marathon Bombings: Preparing for and Responding to the Attack*, 113th Cong. (2013), 5, https://www.hsdl.org/?view&did=740471.

[300] Ibid., 5.

[301] *Testimony before the House Committee* (Schwartz), 3.

[302] Henry Grabar, "Boston Is One of the Best Prepared U.S. Cities to Handle a Crisis," CityLab, April 19, 2013, http://www.theatlanticcities.com/neighborhoods/2013/04/boston-one-best-prepared-us-cities-handle-crisis/5308/.

[303] Grabar, "Boston Is One."

Boston was called Urban Shield.[304] To the exercise, Boston used UASI grant money and hired the CyTel Corporation. This corporation sets up and manages exercises like Urban Shield and is nationally a recognized provider with the best system for preparation and mitigation of incidents.[305] The exercise in 2011 involved 50 agencies and more than 600 people.[306]

The dedication of the working group did not stop at training meetings. Responders and related agencies used some of the UASI money to purchase interoperable radios, so all agencies could communicate easily among themselves and medical staff during the marathon.[307] They also staged emergency ambulance units and EMS along the course. In addition to the ambulances, there were medical tents set up to provide care for runners and patrons. The tents were staffed with paramedics, nurses, and doctors at one-mile intervals; police and fire personnel were also staged along the way.[308] During the race, there were an additional 16 ambulances staged near the finish line and out of what became the blast area.[309] Kurt N. Schwartz, Undersecretary of Homeland Security and the director of Massachusetts Emergency Management Agency, recognized the work and diligence put forth in the planning and training prior to the marathon.[310] He further recognized that this type of leadership was reminiscent of the homeland security enterprise in "all five mission areas—prevention, protection, mitigation, response, and recovery."[311]

Crowded streets presented some problems for pedestrian movement after the bombs went off, but there were no incidents of crowd crush reported. Interlocking bicycle fencing, blocked side streets, public transportation, and closed shelters all contributed to the difficulty in finding an easy exit for people fleeing from the bomb scene. Bicycle fencing

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[304] Ibid.

[305] "Urban Shield: Preparedness at Its Best," Hendon Publishing," 2012, http://www.hendonpub.com/resources/article_archive/results/details?id=1164.

[306] Grabar, "Boston Is One."

[307] *Testimony before the House Committee* (Schwartz), 3.

[308] Ibid., 72.

[309] Ibid., 39.

[310] Ibid.

[311] Ibid., 3.

had been used to separate race fans on the sidewalks from the athletes running the race. The fencing interlocks and is almost impossible to take apart. It is used to funnel fans either right or left along the street they were standing on, not always in the proper direction, causing some to run toward incident scene.[312] The fencing also prevented fire, EMS, and police from gaining quick access to injured victims initially.[313] Public servants and their vehicles also became barriers for people trying exit on side streets. Egress was limited and prevented entirely on side streets in several areas due to incoming emergency responders who were trying to arrive at the scene.[314] Transit police shut down all modes of public transportation to decrease the chances of the bombing suspects escaping. However, the closure almost stopped the crowd's ability to exit the scene.[315] Buses and shelters had been staged and made available to the runners in the event of an emergency; however, the buses were cancelled since they were not used earlier in the day. Shelters were not staffed or opened since most of the runners had finished the race, which meant runners had to look elsewhere for a safe place to stay.[316]

c. Root Cause

In preparation for the marathon, public agencies had formed a mutual aid system for eight different cities to act as one.[317] Planners methodically calculated the entire race and envisioned and planned for most every conceivable calamity with prevention, preparation, and mitigation as their foundation.[318] Unfortunately, it was not possible to prevent for the acts committed by the suspects, who placed improvised explosives in the crowd near the finish line—this was the root cause of the Boston Marathon bombing. The response by the trained professionals and the unexpected help and response from the public was tantamount to the successful mitigation of the medical emergency; the results of the

[312] Massachusetts Governor's Office, *After Action Report*, 94.

[313] Ibid.

[314] Ibid., 116.

[315] Ibid., 44.

[316] Ibid., 96.

[317] *Testimony before the House Committee* (Schwartz), 4.

[318] Ibid., 3.

bombing could have been far worse. The following are some of the issues that impacted egress and emergency response:

- Outstanding interoperability among public agencies. However, private entities working for the event were not trained as well with the new radios and experienced communication problems during the incident.
- There was no public address system or means of communicating with the thousands of runners and spectators.
- Interlocking fences prevented the public form exiting the scene quickly.
- Fencing also prevented quick access to victims by emergency responders.
- Side streets were blocked by emergency vehicles trying to get to the scene, preventing safe egress of the spectators and runners.
- First responders blocked their own access on side streets as they were trying to gain entry to the scene.
- Streets and mass transportation were closed to prevent the suspects from escaping. The action also prevented people from leaving the downtown Boston area.
- Buses should have remained on scene during the entire race, and shelters should have been open and available.

4. Travis AFB Air Show

Travis AFB is located in Fairfield, California and hosts an annual air show with both military and civilian aircraft performing demonstrations. The 2014 air show was billed as Thunder over Solano and more than 100,000 fans attended on May 4, the second day of the show.[319] At approximately 2:00 pm, the pilot of a 1944 Stearman Biplane was performing an inverted maneuver to cut a ribbon with its tail.[320] The pilot made three attempts to cut the ribbon, and all three had failed. The pilot made a fourth attempt and contacted the ground, sliding almost 800 feet down the runway. The aircraft remained on the runway a significant distance from the crowd (see Figure 14).[321] The pilot was

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[319] Shawn Brouwer, "Pilot, 77, Killed in Crash at Travis AFB Air Show," *KCRA*, May 5, 2014, http://www.kcra.com/article/pilot-77-killed-in-crash-at-travis-afb-air-show/6413477.

[320] Wimmer, "Webinar Reviews EMS Response."

[321] Nicole Hensley, "Biplane Crashes at Travis Air Force Base Air Show," *NY Daily News*, last updated May 4, 2014, http://www.nydailynews.com/news/national/biplane-crashes-travis-air-force-base-air-show-article-1.1779300.

uninjured initially but was upside down and unable to get out of his plane. He radioed for help as his plane caught fire. Unfortunately, he died because of the fire. Although the outcome of the incident was tragic, there was no injury to or involvement of the fans. This incident was unlike the Reno Air Race, in which the aircraft were flying directly at the crowd at high speeds.

After the plane crashed, the air show announcer quickly and calmly spoke over the public address system informing the fans that an incident occurred, and they were safe. He also informed them that they must allow the fire department to do its job.[322] Although fans' first inclination was to go toward the incident, they remained calm and compliant behind the barriers. Although the fans were safe, the layout of the airshow and operations proved to be a problem for the air show, and this could have posed a safety hazard for the crowd.

a. Crowd Structure

Fans arrived at the Travis air show on May 4 and were directed to the parking area near the static aircraft display and concessions area. Like the day before, there were 100,000 people attending the demonstration that day.[323] In anticipation of warm weather, the website for the airshow advised people to bring chairs, strollers, nonalcoholic liquid, and sun protection.[324] The crowd was able walk among the static displays of aircraft and along the taxiway. The public's only boundary was marked by fence. No specific areas were designated for viewing or seating as is typical for many outdoor venues (see Figure 14).

[322] SymplMan81, "Travis AFB Air Show Crash 2014," YouTube," May 4, 2014, https://www.youtube.com/watch?v=eRoP07N5uoc/.

[323] Brouwer, "Pilot, 77, Killed in Crash."

[324] Mark Loper Photography, email to author, June 29, 2017.

Figure 14. Schematic of Air Show and Aerial Picture with Crash Site in Lower Right[325]

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[325] Source: Mark Loper Photography, email to author, June 29, 2017.

b. Causal Factors

Planners at Travis AFB considered several factors for the safety of the air show. FAA and NTSB compliance, fire department response, footprint of the air show, and medical facilities were all part of planning for the venue to achieve complete public safety. Planners used NFPA Standard 101 for Life Safety, 403 for Airport Firefighting, and many other standards too numerous to list for general firefighting operations.[326] Standards 101 and 403 are part of hundreds of standards covering all aspects of firefighter equipment and general operations at any location. Standards 101 and 403 describe the responsibility for medical and life safety, while Standard 403 describes the required vehicles and equipment necessary to fight aircraft fires.[327] Additionally, it details responsibility for fire/rescue equipment by indicating equipment should be stationed to have the shortest possible response distance and time to an incident.[328] In the final planning briefing document, NTSB and FAA jointly stated that the Travis fire department administration accepted the submitted procedure before the air show.[329] Morning briefings confirmed acceptance for all standards and directives by all agencies.[330]

The planning operation involved conflicting information, which challenged Travis's goal to maintain safety. Part of the planning document provided by administration at Travis AFB indicated that aircraft rescue and firefighting (ARFF) vehicles would not allow a slowed response during an emergency.[331] In the briefing, firefighters were told, "Emergency vehicles will be pre-positioned…as not to be trapped behind the crowd control lines."[332] However, the same document directed personnel to position aircraft and

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[326] National Transportation Safety Board [NTSB], *National Transportation Safety Board Aviation Accident Final Report* (Accident Number WPR14FA182) (Washington, DC: National Transportation Safety Board, 2014), https://app.ntsb.gov/pdfgenerator/ReportGeneratorFile.ashx?EventID=20140504X90153&AKey=1&RType=Final&IType=FA.

[327] Ibid.

[328] NTSB, *Aviation Accident Final Report.*

[329] Ibid.

[330] Federal Aviation Administration, "Travis AFB NTSB Batch Brief," May 4, 2014, http://www.asias.faa.gov/pls/apex/f?p=100:17:0::NO::AP_BRIEF_RPT_VAR:WPR14FA182.

[331] NTSB, *Aviation Accident Final Report.*

[332] Ibid.

emergency vehicles so they would not obstruct the view of the public. The NTSB observed and supported the U.S. Air Force instruction *Conducting Air Force Open Houses*, which states, "The safety of the spectators is of utmost importance."[333] The result was conflicting orders for fire department response to an emergency.

During the emergency, ARFF 1 left the fire station and drove around the perimeter to get to the incident location rather than driving directly through the static display area. The decreased distance would have shortened the response time for firefighters to get to the burning aircraft. Fire station 1 was the primary emergency response vehicle for aircraft impact, and vehicles from station 3 and 4 would follow if needed.[334] Station 1 was located behind the crowd line, which conflicted with instructions from administration. Both stations 3 and 4 were posted at shorter distances than station 1, and there was no crowd in front of them. However, their staging position also conflicted with administration orders for a quick response to an emergency.[335] Additionally, the designated driving path for all vehicles from stations and staging was the along perimeter of the airshow, which would slow the response time.

The contradictory orders and layout prompted commentary from a NTSB spokesperson, who said the configuration did not meet the requirement for crash fire rescue response.[336] Travis administrators responded that the public was the priority, and crash incidents were secondary.[337] If an incident would have occurred within the perimeter of the spectator area, a similar response would have slowed the arrival to victims since the fire department was only allowed to travel around the perimeter (see Figures 15 and 16). For the air show layout, see Figure 17.

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[333] U.S. Air Force, *Conducting Air Force Open Houses* (U.S. Air Force Instruction 10-1004) (Washington, DC: Secretary of the Air Force, 2010), http://static.e-publishing.af.mil/production/1/af_a3_5/publication/afi10-1004/afi10-1004.pdf, 34.

[334] Federal Aviation Administration, "Travis AFB," 7.

[335] Ibid.

[336] NTSB, *Aviation Accident Final Report*, 14.

[337] Federal Aviation Administration, "Travis AFB," 7.

The safety of fans was also inhibited by the availability of medical capability. There was one medical facility to serve an estimated 100,000 people at the air show located in an area stretching a mile in length.[338] Figure 17 shows a red cross for the medical tent location; one ambulance and one doctor were stationed there. There were no easily identifiable safety people at the show. Furthermore, air show posters did not indicate the location and availability of medical personnel or how one might contact them in the event of an emergency.[339]

Figure 15. Crowd at Travis Air Show[340]

[338] Brouwer, "Pilot, 77, Killed in Crash."

[339] Mark Loper Photography, email to author, June 29, 2017.

[340] Source: Mark Loper Photography, email to author, June 29, 2017.

Figure 16. Dense Crowd with Chairs and Strollers Held in with Interlocking Perimeter Fence[341]

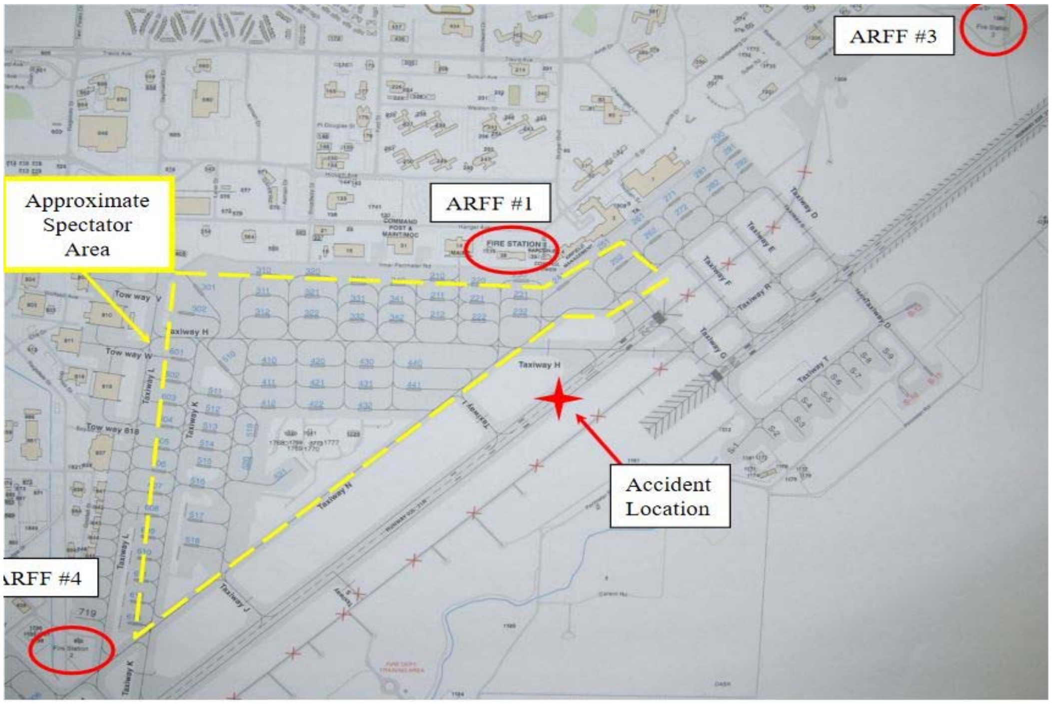

Figure 17. Yellow Line is the Perimeter Fence Holding Crowd[342]

341 Source: Mark Loper Photography, email to author, June 29, 2017.

342 Source: Mark Loper Photography, email to author, June 29, 2017.

c. Root Cause

The study of the incident at Travis AFB did not include problems with crowd movement, although conflicting orders by planners would have created significant potential for patron injury if an incident occurred in the crowd. Therefore, the venue was unprepared and unsafe. ARFF 1 was unable to respond to the downed aircraft quickly due to the number of patrons blocking the station apparatus doors.[343] Presumably, the same problem can have arisen in the event of an incident inside the static display and viewing area. NTSB reported planners at Travis AFB "stated" that during practice, before the air show, there were no patrons.[344] Those conducting the practice did not consider what conditions would be like with the venue filled with people.[345] The following are causes for conflicting information and unsafe practices:

- Planning for the event should have included absolute acceptance of the orders and standards to prevent conflict.
- Slowed response was not acceptable; however, ARFF was not allowed to drive in a direct route, which conflicted with FAA rules.
- Because organizers at Travis AFB prohibited fire response from driving near the crowd, they ordered ARFF to drive around the show perimeter during emergencies.
- There were no emergency driving lanes at the venue.
- There was one medical facility staffed with one doctor.
- One ambulance was staged near the medical facility.
- Bike medics were not deployed and are commonly used in Sacramento

D. SUMMARY OF CASE STUDIES

There are many factors discussed in the four case studies that point to their respective root causes. Regardless of the differences in the type of venue, they share similarities that contributed (or may have contributed) to the outcome of the incidents. All events discussed in the case studies had large crowds at an outdoor event. The numbers of

[343] NTSB, *Aviation Accident Final Report*, 12.

[344] Ibid.

[345] Ibid.

individuals at the venues and their density created the potential for injury and the inability for emergency personnel to gain access. Of the planners in the four studies, only Hillsborough planners consulted the Green Guide to calculate the number of people allowable in the space provided, although they then completely disregarded the recommendation. Planners in the other studies did not appear to the use of the Green Guide or similar reference to determine the maximum number of people allowed for the venue space. In addition, ticket sales and patron registration were the only indicators that planners of the Hillsborough match could have used to determine crowd numbers; however, ticketless fans were allowed entry at the venue. Considering the size of crowds involved at the four venues, interoperability should have been a factor for all venues. However, emergency responders and volunteer staff at the Boston marathon were the only event in which responders and staff used up to date communications. Police specifically indicated radio problems at Hillsborough.

Communications are routinely a problem at an any emergency scene and are compounded with different agencies working together. Communications in and among agencies at big events is a key issue; however, only the planners at the Boston Marathon considered them, which proved to be a boon for multiple agencies. Organizers of both the Reno Air Race and Boston Marathon planned and held drills to determine possible types of potential problems and how to prevent or mitigate them. They thought ahead by creating scenarios of the very calamities they later encountered. Additionally, these pre-event drills helped them to establish working relationships and build trust among different agencies. Reports on the Boston bombing specifically note the trust among agencies, which allowed them to work so well together. Also, notable in the Boston case study is the mutual aid among the eight cities involved in the race and their ability to work together. The planning agencies involved with the Reno case study also experienced the same working relationships during the race incident.

Lastly, communication is one of the most important factors at any incident, and planner should consider communications in preparation for events. Of the four case studies, officials at Travis AFB were the only ones to use a public address system. While responders dealt with the crash, an announcer continually instructed the crowd to remain calm and remain behind barriers for their safety; this service kept the crowd informed and safe. The same procedure could have been used at all other venues in the case studies, and had it been, it may have prevented injuries. The size of the venues was not an issue. Organizers could have used an address system with WIFI and blue tooth capability. For example, Boston planners could have easily provided an information system along the entire 26.2-mile trek, which would have facilitated additional safety and security.

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V. FINDINGS AND RECOMMENDATIONS FOR FIRE DEPARTMENT PLANNING

The challenge with crowded venues is the inability of people to move and exit smoothly. The challenge increases during a perceived or actual emergency. It is important for fire departments to understand how crowds develop and move at outdoor events. Their primary responsibilities include prevention of harm through pre-planning at events and also care and transportation of the sick and injured. Predicting crowd behavior can prevent injury as people enter and exit venues.

A. FINDINGS

This research has identified common problems due to human behavior and their interaction with the environment that occur with crowds during emergencies. Fire departments use information from former events to prevent and mitigate problems during planning and response at incidents with large crowds. The result should decrease the response time to get fire, police, and EMS to the scene of an incident and increase life safety. The information is arranged in eight sections the follow: crowd behavior, variable crowd speed, density (how closely people stand together), immovable barriers become hazards, staged resources decrease response time, inability to communicate with a crowd creates problems, comprehensive planning/training, and unified command brings organization.

1. Crowd Behavior at Outside Venues

People can die of asphyxia if they fall in a dense crowd while it is moving. Moving like water in a stream, crowds may also be hampered by their ability to move freely due to obstacles such as people, sudden movement, turnstiles, or other barriers in their path. The incident at Hillsborough highlights this problem. During the Boston incident, there were problems with crowd movement because of interlocking fences that kept people on narrow sidewalks during an incident, interfering with their ability to find safe egress from a chaotic scene.

An unfortunate aspect of crowd behavior is the way it responds to stimuli. Noise, a real or perceived incident, or sudden movement can spark a reaction that can become dangerous. Announcers were aware of this possibility at the Travis AFB Air Show. An incident occurred when a plane crashed; however, the crowd was quickly calmed by the announcer, who gave them instructions for safety. He also announced updates during the mitigation of the incident over the public address system to ensure patrons safety. Fans at the Hillsborough soccer match did not experience the same calming effect when police were attempting to safely move the crowd into the stadium. The unfortunate response was crowd crush as the fans moved through an auxiliary gate that the police opened to relieve pressure on the inadequate turnstiles. The result was hundreds tripping, falling to the ground, and getting crushed by the crowd or being crushed against fences.

2. Walking at Different Speeds Can Create Problems in a Crowd

Individual groups form within crowds and travel at different speeds. Subgroups traveling at different speeds in a crowd can increase the possibility of individuals tripping or falling and sustaining an injury. Additionally, crowd make-up changes with the type of venue, and different type of patron attending the event. For example, sporting events like the Boston Marathon attract adults, children, and elderly, who all differ in size and walking speed. People using strollers, walkers, or wheel chairs walk slower. Motivated by attractions, food, and bathroom locations at the event, people also change direction and speeds when walking in crowds, which further affects the crowd. When people change their walking speed in a heavily populated venue, it can disrupt the forward progression of the crowd, much like what happens in a traffic jam. It then takes a few moments for the crowd to start up again and move in a forward generally direction. These problems emerged at the Hillsborough match as people continually changed direction as they tried to gain entry prior to the gate opening. Also, the air show at Travis AFB had very dense crowds, and people brought their own folding chairs and strollers. These are items that could create exiting problems and trip hazards in an emergency.

3. Density (How Closely People Stand Together) Affects Travel at an Event

When people enter an event, they begin to form groups. As more people enter, the groups become larger. Depending on the venue, it is possible to have more than 100,000 people at one event. The area where the crowd stands may be limited by fencing, which limits the number of people at the venue for safety. People individually move toward the area of entertainment, closing the distance between them and the person in front of them. Closing this gap increases the density of people in a given space. The incident at Hillsborough is a perfect example of what can happen when too many people try to occupy too small of a space. Crowds densities of five or less people per square meter allow patrons to walk and change direction without incident, while six or more people per square meter present certain danger should a person slip or fall.[346] People become so close at six people per square meter that it causes them to bump into each or fall to the ground. The 1989 incident at Hillsborough had densities of 12 or more people per square meter, causing 96 deaths and more than 200 injuries during the crowd crush. Research into other case studies in this thesis did not indicate that crowd density was responsible for any injury.

4. Immovable Barriers Become a Hazard

Barriers to control crowds and traffic can become a safety hazard if not properly used and installed or easily movable. There were problems associated with the types of barriers at both the Boston and Reno events, and this led to egress problems. For example, in front of the bleachers, organizers at the Reno Air Race used fencing to construct preferred seating areas with multiple tables, chairs, and umbrellas for more than 1000 patrons. The furniture then became obstacles. In the Boston event, installed and interlocking bicycle fencing prevented patrons from quickly escaping the area, which was compounded by the shutdown of public transportation to prevent the bombers from fleeing the area. In the process of trying to respond to the rescue area by side streets many fire, police, and EMS vehicles ended up blocking side streets, which also limited patrons' ability

[346] Helbing, Johansson, and Al-Abideen, "The Dynamics of Crowd Disasters."

to exit the area. The action by the city, essentially held patrons, runners, and volunteers in a small area with no direction for egress.

5. Staged Resources Decrease Response Time

Staged resources can provide medical care while keeping egress routes open. Some fire, police, and EMS were staged at the Reno Air Race and Boston Marathon. Emergency responders understood that crowd density as well as traffic in and out of a venue would significantly increase response time in the event of an emergency. They placed vehicles and personnel at strategic locations, significantly decreasing response time to the incidents. Planning locations in advance also keeps human and vehicle traffic flowing at a venue as it did at some locations in Boston. In the Boston and Reno incidents, fire and EMS were credited by area trauma hospital physicians with saving lives. As a result of proper planning, patients were transported very quickly from the multicasualty incidents. Organizers at both venues recognized and understood the importance of readiness. The survivability of patients was increased by the fire and EMS response time.

6. Inability to Communicate with the Crowd Can Be a Problem

Communication is an inherent problem that has been noted at several of the case studies in this thesis. For example, police at the Hillsborough match specifically noted they were unable to understand orders over their radios. Organizers of the Boston Marathon used a state of the art communication system that worked very well between agencies. They set up an entire network along the 26.2-mile course to provide continual information to and interoperability between agencies. Unfortunately, as at the Hillsborough match, the owners of the stadium or the police did not have a communication system capable of updating and addressing the crowd, which left people uninformed about emergency plans and exits. The incident Travis AFB reveals several communication issues between command and vehicles; however, the public address system provided continual information to the crowd. Announcers updated the crowd during the incident, thus keeping people safe, informed, and prevented chaos while emergency vehicles arrived.

7. Comprehensive Planning and Training Can Improve Event Response

The case studies revealed that organizers at Hillsborough and Travis AFB did not consider two crucial factors, comprehensive planning and training prior to the events. Organizers in Reno and Boston developed plans that included all emergency responders, as well as all interested stakeholders in the cities. The office of emergency service, emergency planners, hospital coordinators, dispatch supervisors, city council members, Department of Transportation, parking, and many other agencies took part in all planning for the events. Organizers at the events in Boston and Reno clearly stated at planning meetings that no one should be meeting another official for the first time at the scene of an emergency.[347] Additionally, the organizers recognized it was imperative that everyone involved knew and worked with everyone else. In addition to planning at the local and state levels, organizers of both the marathon and air race held drills. Reno used actors with makeup simulating wounds and injuries so that participants would become familiar with all aspects of an emergency. The mock patients were put in treatment and triage areas and then transported to hospitals to make the drill as realistic as possible. Area hospitals credited the simulations for saving the lives of people in Reno. Boston used table top scenarios and was later given praise by Governor Patrick, who recognized the speed of care and organization that would not have been possible without previous training and the trust developed by working together.[348]

Planning and training breeds familiarity, knowledge, and trust among everyone working at an emergency scene. As Archilochos astutely noted, “We don’t rise to the level of our expectations, we fall to the level of our training.”[349] Officials in both Boston and Reno understood also that the associations made during planning and training would become a force multiplier for future venues or incidents. The knowledge obtained in training could be carried and taught to others by emergency responders and public officials.

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347 Committee on Homeland Security, *Lessons Learned*, 5.

348 Ibid., 6.

349 Archilochos, “A Quote by Archilochos,” Goodreads, accessed October 15, 2017, https://www.goodreads.com/quotes/387614-we-don-t-rise-to-the-level-of-our-expectations-we.

8. Unified Command Brings Organization

Unified command is part of planning and the incident command system.[350] It should be used when more than one agency is at an emergency or planned event for an extended time period.[351] In the case studies personnel in only two events, the Reno Air Race and the Boston Marathon, used a unified command system.[352] Planners of both events recognized the need for the organization that unified command brings to an event. Boston Marathon's unified command center was located at the Westin Hotel, near the scene of the bombing. In addition to fire, law, and EMS, the mayor, and governor were located at the command post.[353] While public safety was taking care of the scene, the mayor and governor assisted by declaring a state of emergency and calling on additional emergency responder assets to assist in mitigation of the scene.[354]

B. RECOMMENDATIONS

This section contains recommendations, based on data on crowd behavior and the case studies, particularly common problems, to assist fire departments with pre-event planning to decrease the possibility of injury at crowded outside events. They have been divided into eight sections and arranged from the beginning of an outdoor event to the opening day. Each section has information supporting other recommendations provided. The sections are: stakeholders, planning, training, staffing, communication, overcrowding, supportive measures, and education.

1. Establish Relationships among Stakeholders before Events

Stakeholders are tremendously important to the success of an event at an outdoor venue. They make decisions and offer approval for public agencies to provide the required services needed to protect the public at events. Depending on the type of event, they may

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[350] FEMA, *NIMS and the Incident Command System*.

[351] Ibid.

[352] Massachusetts Governor's Office, *After Action Report*.

[353] Ibid., 5.

[354] Ibid., 66.

include officials from local, state, and federal agencies, as well all related agencies in the proposed venue. The governor, mayor, city council, county supervisors, Office of Emergency Services, fire, police, EMS, Department of Transportation, Department of Health, local emergency medical authority, hospitals, parking, and sanitation are all stakeholders to consider for planning. Boston fire, police, and EMS understood the need for buy-in from stakeholders in planning for the marathon. Organizers for the Reno Air Race also understood the need for bringing stakeholders together; however, they focused mainly on emergency response and delivery. Boston planners were thinking ahead when they brought together all the interested parties to the table to discuss public safety for the pending marathon. They also recognized the importance of working together and that the only way to have a successful venue was to establish working relationships between and among each other.[355] Trust is established by working together and allows for faster decisions at emergency incidents. The Boston agencies working together knew the saying, "You don't want to be exchanging business cards at the scene of a disaster," and they were dedicated to working and knowing each other during the entire process of the marathon.[356]

2. Planning is Essential

Planning for an event is an essential part of any venue and should be conducted by appropriate emergency services and other stakeholders. Both Reno and Boston conducted comprehensive planning and working exercises that provided outstanding dividends. Their efforts were realized by the professional and expedient care of the wound after each event experienced deadly incidents. In contrast, stakeholders Hillsborough and Travis were not involved with planning or nor did they hold a detailed exercise prior to their events. The case studies in this theses prove that planning has produced positive results.

Planning meetings held in preparation for upcoming events allow fire departments and other agencies to work together. The planning organization may be only a few individuals for small venues or very large like Boston where hundreds attended. Meetings, like Boston's planning meeting, are too large to manage and operate as one group,

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[355] Ibid., 71.

[356] Committee on Homeland Security, *Lessons Learned*, 5.

exceeding the span of control. Therefore, it is important to establish operating break-out groups to develop strategies for managing and organizing situations that need attention. An executive group should coordinate information among city officials, who are responsible for budgeting funds to support the venue and developing funding streams that may recoup expenses for the venue. A safety group consisting of fire, police, and EMS should organize safety and protection. A logistics group brings parking, sanitation, and fencing together and should work closely with the safety group to ensure proper exiting of the event.

3. Training is the Foundation for Safe Operations

Training is closely related to planning since it uses the information developed from planning to understand the needs and the people attending the venue. Training can then be specifically tailored to prevent and mitigate anticipated incidents and threats. The incidents discussed in Chapter II did not reveal any information about training prior to their events. A panel on the Hillsborough match produced a detailed report and findings for the outcome of the incident; however, in it, here was no indication of any training or organization before the soccer match. Organizers for the air show at Travis AFB also did not provide training involving stakeholders prior to the air show. In contrast, organizers at both Reno and Boston understood the possibility of an incident, and they established working scenarios for multiple possibilities at the venues.[357] These scenarios were initially performed as table top exercises.[358] Use of a tabletop exercise allows the introduction of new questions and possibilities to incident mitigation, which can then be injected into training scenarios. Additionally, tabletop exercises also allow stakeholders to understand the scope of an incident and the requirements necessary for emergency scene mitigation. After table top exercises, the next step is to perform a realistic live scenario. All agencies related to scene response and mitigation should be involved just as they were in the live exercise held in Reno. In the Reno exercise, 50 agencies participated. During the Boston exercises, 600 agencies participated.[359] In both the Reno scenario, actors mimicked an aircraft disaster

[357] Nelson, “Hundreds Team Up.”

[358] Ibid.

[359] Ibid.

and the problems associated with care and transportation of the resulting patients. There were no shortcuts; the scenario operated as real disaster. Organizers used findings at the end of the scenario were to set up emergency services at the Reno Air Race. The training at Reno proved to be a benefit by the expedient way the incident was mitigated.

4. Interoperability is Also About Communication

Communication is a common problem at venues and incidents. The problems established with communications at the venues this thesis discusses could have been prevented by providing proper training for all workers with radios and setting up a public address system to help inform the public and participants. Location, noise from the crowd, and capability of radios are all factors that can contribute to radio failure when responders are establishing safety for the public. The independent report for the incident at Hillsborough soccer match specifically indicated there were communication problems between police officers in the command center, on horseback, and on foot.[360] The results of communication problems can prevent proper decision making may affect the survivability of any or all the injured individuals at a venue or incident. Members of the grunge band Pearl Jam attempted to use a public address system at a Dutch concert to stop crowd crush by asking the people in the crowd to each take three steps back, slowing their forward progression.[361] Announcers at Travis AFB successfully used a public address system to inform the patrons of the crash and keep them calm during the incident at the air show.[362]

Planners for Boston Marathon specifically addressed the probability of communication problems along the 26.2-mile route and through eight different cities while using different types of radios. Planners attempted to prevent communication problems by obtaining grants to purchase an interoperable radio system allowing communication across all bands of the radio seamlessly.[363] The system worked very well with emergency

[360] Hillsborough Independent Panel, *Hillsborough*, 9.

[361] Associated Press, "8 Crushed to Death at Rock Festival."

[362] SymplMan81, "Travis AFB Air Show Crash 2014."

[363] Massachusetts Governor's Office, *After Action Report*, 111.

agencies. However, some volunteers were unfamiliar with the use of the radios and consequently were unable to receive updated information as it became available.[364] Mistakenly, the radios were not programmed to work with public service bands.[365] This prevented workers from updating and directing runners at the race. The planning for the marathon did not include a public address system downtown or along the route to update fans or athletes, which meant they arrived at a chaotic scene with no direction for safety.

5. Volunteer Staffing is an Essential Part of Planning

Volunteers can be a significant asset for fire departments and for the communities they serve and not just in emergencies. They should be included at public events to increase safety for the patrons attending. They are trained for several disciplines that aid during planned events and emergencies; CERT members are an asset for fire and police departments. Additionally, CERT provides support by assisting at medical tents, triage, crowd management, communications, and transportation, and fire departments should take CERT services into consideration in planning for events at crowded venues. Volunteers can also staff shelters and drive buses at large venues. Planners in Boston were thinking ahead when they considered the number of runners and volunteers at the race. City officials secured multiple shelters and provided buses to transport athletes to shelters in the likely possibility of an incident.[366] However, information after the event revealed the shelters were not staffed, and the buses were sent away, since it was determined they would not be needed. The buses and shelters could have been used for the 5,000 runners that had not yet arrived at the scene of the incident, keeping them from adding to the already chaotic scene.

6. Overcrowding Can Be Prevented with Proper Planning

Overcrowding at outdoor venues is an ongoing problem regardless of death and injuries at past events. As recently as July 2017, a crowd of thousands assembled to watch a soccer match in Turin, Italy. When a prankster lit some fireworks, the crowd believed the

[364] Ibid.

[365] Ibid.

[366] Ibid., 21.

noise was gunshots and the resulting crowd crush injured 1,500 people.[367] Organized use of fire department inspections, Green Guide recommendations, fitting the venue, ticket sales, and registration are all means of preventing overcrowding.

Specifically, the panel on the Hillsborough incident reported that the fire department performed inspections on the stadium and owners adhered to adherence to fire ordinances. The panel's report also cited many infractions that should have limited the use of the facility; however, owners and the police department disregarded the report.[368] Organizers of the Hillsborough match consulted but did not use the standards in the Green Guide, an internationally recognized publication to determines capacity at venues. The information would have helped to make sure that the crowd size fit the venue. In other words, the calculation in the Green Guide would have shown organizers the proper size of crowd for the capacity of the stadium. In addition to ordinance and calculations for maximum capacity, two other methods can be applied to keep the crowd to regulated size. First, ticket sales determine the number of individuals allowed at an event. Second is by the use of online registration, which can be halted when the maximum number of participants have been reached. The registered patrons would print a ticket that could be collected at the venue. The independent report of the Hillsborough incident in 1989 reported ticketless fans contributed to crowd size, but no one prevented them from gaining entry.[369] Holding tickets is an absolute means for police to determine the number of fans allowed at a venue.

Other problems arise from events that are free like the Love Parade, where an estimated 1,000,000 music fans arrived in one day. For instance, it is impossible to control the number of fans arriving at a free venue unless registration or tickets sales are provided and managed at the gates. However, one method to monitor and prevent overcrowding is to mandate online registration by fans. They would have to bring the printed registration

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367 Reynolds, "Turin Stampede."

368 Hillsborough Independent Panel, *Hillsborough*, 66.

369 Ibid., 10.

number to gain entry. This would also require security at the gate to prevent unregistered individuals from entering.

7. Supportive Measures to Decrease Crowd Density

This section suggests recommendations that do not fit in any particular category but are nonetheless important. Related to the recommendation to "fit the venue," another possibility is for event organizers to merely change the size of the grounds and find another location that to accommodate the anticipated crowd. Jumbotrons or large TV monitors should be placed in areas to allow the crowd to move to less densely populated areas of the venue. This practice is common at some sporting events and concerts to give patrons optimal viewing. Another means of preventing crowds from all moving to one location is to provide a theater in the round, moving stages, and multiple stages located at opposite sides of the venue. These are strategies that help spread out the people and prevent dense crowds. There are also some methods that can be used to slow the traffic as people enter, thus spreading the crowd out to prevent bunching up and possible injury.

As part of the planning phase of any venue, there are some strategies to help manage the patrons as they enter and locate seating at an event. A will call booth should be set-up away from the main entrance for last minute tickets or registration. Multiple entrances should be available to prevent a bottlenecks and slow patron entry as at the Hillsborough soccer match. Security should check tickets away from the entrances to facilitate movement of the fans into the venue. Events that do not provide seating should have clearly marked areas where folding chairs or blankets can be used. Water filled jersey barriers can mark isles for entrance and egress of a given area; however, planners need to be cognizant of crowd capacity in these areas. Lastly, emergency vehicle lanes should be provided on all main streets to decrease emergency response time and increase safety.

8. Educating People Will Make Them Safe

Education is certainly not the least important recommendation for safety and crowd control. As previously stated, all the recommendations work together to provide optimum safety and crowd density reduction. The following strategies are related to steps that people already observe; they may not often think about the education they are receiving to make them safe. For example, the first item anyone receives after purchasing a ticket at theme park is a pamphlet that includes the times for attractions. More importantly, a map explains where every attraction is located, bathrooms, food, exits, and emergency phone numbers in case of an incident. Airlines offer fliers safety information with their three-minute informational speech about safety. Schools routinely teach children about fire safety and conduct regular fire drills. Many businesses also practice safety training to ensure the safety of their employees. This thesis recommends that organizers of large events provide the same type of informational pamphlets to people as they enter a venue. The information should also be provided on social media prior to the opening of the event and updates sent through interactive app on attendees' phones. At large outdoor events, announcements should be made periodically at the venue over public address system and social media to remind patrons about the importance of safety and the locations where patrons can find care or assistance. In addition, venues should feature large, easily seen exit signs and exit arrows, which can be painted on the ground, grass, or pavement, just as large stores do. These educational methods would allow people to become accustomed to safety instructions just as they have learned from fire drills and airplanes.

C. CONCLUSIONS

This thesis has explored how crowds respond during an incident that may result in their injury or death. It could be a sudden weather change, noise interpreted as a gunshot, movement in a crowd or other man-made event. Crowd reaction in an emergency is not necessarily a flight response as described by Fahy, Proulx, and Aiman. They indicate that crowds do not truly panic but make decisions based on their information for exiting.[370] Crowd reaction at the Reno Air Race proved that people do not run maniacally in any direction seeking safety, instead they can move methodically to exits from the bleachers. Helbing and Johansson also support the theory that people can make judgments in an emergency.[371] However, researchers in the science of crowd dynamics and safety are not all on the same page. Some are opposed to any theory other than their own, like Yanagisawa

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[370] Fahy, Proulx, and Aiman, "'Panic' and Human Behaviour."

[371] Helbing and Johansson, *Pedestrian Crowd*.

et al. who advocated barrier use.[372] However, all the case studies in this research include problems related to barriers during the incidents. Other researchers are not in favor of installing barriers.

Researchers also continue to try and explain the phenomenon of crowd crush and have developed software mimicking human movement and reaction while attempting to evacuate buildings, aircraft, and stadia through turnstiles in emergent situations.[373] It appears that there is more research on how injuries to humans happen rather than how to prevent them from happening. Fruin's research that advocates what would seem obvious; keep crowd size manageable and crowd densities to a minimum.[374]

It is difficult to find information about crowd dynamics related to fire department planning and safety information. Therefore, fire departments should work with law enforcement to apply information on crowd dynamics to fire department operations. It is important for fire departments to follow-up with organizers of events and follow current ordinance for public safety and determine the available space at venues. The space available determines the number of people that can be placed in the given area.[375] The crowds are going to continue to gather at favorite events.[376] It is the responsibility of public agencies to monitor and assist organizers in developing safe venues to prevent injury to the patrons.

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[372] Yanagisawa et al., "Introduction of Frictional."

[373] Galea, "Scientists Launch World's Most Advanced."

[374] Fruin, "The Causes and Prevention of Crowd Disasters."

[375] Department for Culture, Media and Sport, *Guide to Safety*.

[376] Health and Safety Executive, *Managing Crowds Safely*.

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